# CLIMATE IN EVERYDAY LIFE

*By the same author*

THE EVOLUTION OF CLIMATE

CLIMATE

BRITISH FLOODS AND DROUGHTS

THE WEATHER

CLIMATE THROUGH THE AGES

# CLIMATE
## IN EVERYDAY LIFE

*By*

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# PREFACE

THIS book sprang from a short paper which I contributed to the Royal Meteorological Society in 1946, entitled "Climate and the Deterioration of Materials." Requests for reprints far exceeded the supply, and it seemed that a small work on this and other applications of climatology to industry might serve a useful purpose. So I began a book on "Industrial Climatology," which, by a natural process of assimilation grew into the present book.

The literature of the subject is so immense and so widely scattered—much of it is published in trade and technical Journals—that I cannot hope to have seen more than a small part, though I have been greatly helped by those workers in technical research who have kindly sent me reprints of their papers, and by the Librarian of the Meteorological Office, who has called my attention to other new work. Moreover, no one man can grasp all the technical complications of modern life, and I have no doubt made some howlers for which I ask forgiveness from the specialists.

Acknowledgments are due to the Air Ministry for permission to reproduce the anemogram in Fig. 12, to the Royal Meteorological Society for Figs. 14 and 17, to the National Smoke Abatement Society for Figs. 20, 21 and 22, and to Dr. J. M. Stagg for permission to use the material of table 9 in advance of publication. Some of the other illustrations have been reconstructed from figures or diagrams published by other workers; the source of these is acknowledged in the text. I am indebted to Miss E. H. Geake and Dr. J. Glasspoole for criticism and advice on climatological matters, to Commander Hennessy for help with the section on sea ice, to Miss N. Carruthers for reading the whole of the text and playing the role of candid friend, and to Miss M. E. Robinson for making fair (I should say, fine) copies of the maps and diagrams. My wife has, as usual, helped in all stages of the book.

C. E. P. BROOKS.

South Ferring, 1950.

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# INTRODUCTION

PRACTICALLY every action of human life is directly affected by climate. The food we eat, the clothes we wear, the house we dwell in, the work we do, are all dominated by the climate in which we have the good or bad fortune to live. Not only is our life governed by weather and climate, but so also are the energy with which we live it, and the good or bad health which we enjoy. The efficiency of any group of people, such as a school or college, a body of professional men, or the personnel of a Government department, factory or office is closely bound up with the climatic conditions in which they work and live. A stimulating and health-giving climate is actually worth a very large sum in solid cash, to say nothing of happiness, to the country fortunate enough to possess it. Not all countries are so fortunate; many parts of the world are hot and enervating, others have long monotonously cold winters. But these conditions should be regarded as a challenge rather than as a discouragement, for much can be done by suitable housing, air conditioning, clothing, sanitation and in other ways to minimise the ill effects. This has been shown in such places as the Panama Canal Zone, once notoriously unhealthy, where wise organisation has brought life and health up to a level little inferior to that of the centres of civilisation.

A word is required here about the distinction between "weather" and "climate." "Weather" is the aggregate of atmospheric conditions at any one time in any one place; it changes from day to day, while "climate," which is the whole long-period assembly of weather conditions, goes on all the time. Our day-to-day activities are more or less affected by the day-to-day weather, but the general pattern of our lives is governed rather by the climate. The city dweller who goes off to work every week-day, organises his life to suit his climate; it is only at week-ends and on holidays that his actions are dominated by the weather (or the weather forecast). That is why I have called this book "Climate," and not "Weather," in Everyday Life.

Since the needs of the people in all countries are largely decided by their climates, and since it is the province of industry

and commerce to supply these needs, the business man is especially concerned. He must suit his activities—what he sells, when and where he sells it—to the prevailing weather in his markets. Hence a good deal of this book aims at helping the business man in his decisions. To take an absurdly extreme case, no business man would export fur coats to the Equator, or refrigerators to Greenland! But the effect of climate goes much further than that. The manufacturer, having decided what he will make, has to decide where he will make it. Some products require special conditions, dry or damp air, freedom from soot or dust, a moderate or high temperature. Many industries are affected by rapid or large changes of temperature, especially the paint and varnish, electrical insulation and textile industries. The ease of manipulation of plastic materials is affected by temperature. Humidity affects printing; the size of paper changes with the relative humidity, causing loss of accuracy in multi-colour work; on the other hand, in very dry air friction in the presses produces static electricity which is a source of trouble. Dust is the enemy of all kinds of delicate machinery. These are only a few examples; the list is endless. In choosing the site of a factory all these climatic factors have to be balanced against each other and against considerations such as ground and building costs, labour, cost of transport, etc.

The product having been made, it has to be packed. Some articles, such as cosmetics, confectionery and photographic supplies, are very sensitive to moisture, especially if the latter is combined with heat or rapid changes of temperature. If such goods are to be exported to a moist, tropical country, or even if they have to pass through such country on their way to their destination, special packing may be required. In certain climates air-tight packing is necessary. Canned goods may have to be coated with a protective varnish, or the labels affixed with waterproof gum. But such precautions are expensive, and are only to be taken if they are really necessary. Hence the weather to be expected in the market country and along the route to it must be studied to obtain sufficient protection at the smallest cost. Markets might be classified into three or four groups from this point of view, and different, suitable, packing provided for each group. Besides what may be termed the *structural* design of the packing, the *artistic* design (and the

advertisements) may also vary from country to country according to the climate.

Climate is important in other ways. A plentiful and reliable water supply is a necessity for civilised life, and all water supply depends ultimately on the rainfall, either locally or in some more or less remote gathering ground. Hence we must study the average rainfall, its seasonal distribution and its variability, especially the risk of drought. Dwellers on the banks of rivers are concerned with floods. Wind is important in all aspects of life; our buildings must withstand wind pressure; in the country we may depend on wind to pump our water and generate our electricity; in towns the wind carries away from house and factory chimney the smoke and gases which would otherwise stifle us. The sun is the greatest source of light and heat; these essentials can be manufactured, but at a price, the natural article costs nothing. The cost of a town fog in lighting alone is very great. We must be able to carry ourselves and our marketable products from one place to another; hence we must think of fog, snow, ice and other obstacles to transport. We need relaxation, and must care for the natural amenities of life. Finally, since accidents will happen in even the best-regulated climates, we must estimate the risks of blizzards, hurricanes, tornadoes, hail, lightning and other violent disturbers of the peace, and think how far we can guard against them.

The purpose of the following chapters is to provide in a small compass answers to the questions which are most often asked about climate by anyone choosing a site, planning a house, factory or new town, starting up or expanding a business, buying an outfit for a journey overseas, or engaged in any other activity in which the prevailing weather conditions are an important factor. To fulfil this ambitious programme completely would require a large encyclopædia, but it is hoped that the references at the end will round out the outlines in the text. Most meteorologists have had the experience of providing, at considerable labour, answers to the wrong questions. It is hoped that at the least this book will help enquirers to ask the right questions, and so save the time of themselves and others.

The general plan is as follows: Part I is an account of climate from the point of view of the man living in it. Chapter I, "The Economics of Climate," and Chapter II, "The Siting and Design of Houses and Factories in Relation to Climate," are

intended as a primer on the exploitation of natural climatic resources. Chapters III to VII describe briefly living and working in the climates of different parts of the world. In Part II climate is regarded as an enemy to be faced. Chapter VIII describes recent researches into the relations between climate and the deterioration of various sorts of manufactured products. Chapter IX discusses the evil of dirt and dust in the air, and Chapter X all the various disasters from frost to tornadoes which afflict different parts of the world, where and how often they occur. Part III describes how to get over climate by heating and air conditioning, by lighting, by clothing, and by protection from the more violent and disastrous efforts of nature.

Some people like figures, and Appendix I caters for them by giving statistical outlines of the climates of a number of places in all parts of the world. Some people do not like figures, and so each line of statistics is summed up in a brief thumb-nail sketch, based on precise definitions. Finally, since Babel still afflicts climatology, the last page gives a few necessary conversion factors between different systems of units.

# PART I

# LIVING WITH THE CLIMATE

# CHAPTER I

# THE ECONOMICS OF CLIMATE

## CLIMATIC DATA

THE most important elements of weather to be considered in planning human activities are temperature, humidity, rainfall and wind. Good tables and maps of the distribution of temperature and rainfall are available for nearly all parts of the world, and can be bought or seen at the offices of the national meteorological services. Humidity and wind are measured at many weather stations, but are less easily mapped, so that charts showing the distribution of these elements are less readily obtainable. Humidity can be represented in various ways: (1) by the absolute amount of water vapour in the air, measured in grams of water per cubic metre of air, or grains per cubic foot; (2) by the pressure of the water vapour in millibars; (3) by the "mixing ratio," or weight of water vapour per kilogram of dry air; (4) by the "dew point" or temperature at which the air would become saturated; (5) by the relative humidity, or percentage ratio of the amount of water vapour in the air to the amount which it would hold if saturated at the same temperature; (6) by the "saturation deficit" or the difference between the amount of water vapour and the amount which the air would hold if saturated; (7) by the "wet-bulb temperature," which is the temperature of a freely evaporating moist surface. Each of these measures is important for different purposes, as will appear in later parts of this book. A rough conversion table from one to another is given in Appendix II. For practical purposes, when exact data are not available, temperature and rainfall give a fairly good indication of the humidity. Other useful information concerns the frequency of rain, snow and fog, and the highest wind speed to be expected. In order not to overburden the text with tables most of the statistical climatic data are collected in Appendix I. World maps of air temperature for January and July are given in Figs. 2 and 3, and of wet-bulb temperature in Figs. 4 and 5.

*Classification of Climates.*—For quick reference to the climate

of any particular district it is useful to have a map showing the distribution of different types of climate. Many such maps have been prepared by geographers, mainly on the basis of plant life. The main divisions shown on such maps are into regions classified as: Hot; Monsoon (cold dry winters, wet summers); Mediterranean (hot dry summers, cool wet winters); Desert; Temperate; Cold. This makes a good beginning, but for purposes of human activities it needs some modification. I have in Fig. 1 divided the world into nine regions. First we eliminate those parts of the world which have little interest for our purposes:

(1) Polar regions and tundras. These are inhabited if at all only by scattered hunting or fishing tribes; their chief economic product is fur. A convenient boundary is the poleward limit of agriculture.

(2) Mountain regions (general elevation above 6,000 feet). Apart from winter sports and holiday centres and mining districts, these generally have only a scattered population; access is difficult. Large elevated plateaus form an exception especially in the tropics, where such regions are important because of their healthfulness.

(3) Deserts (annual rainfall below 10 inches). Apart from irrigated regions, such as the Nile Valley, and some mining centres, these also are very sparsely inhabited.

The next three climatic regions, though often densely populated, suffer from some climatic disadvantages.

(4) Insolation climates, where the main feature of life is the intense solar radiation. At least once in two years the shade temperature exceeds 110° F., and in some years it climbs to 120° or more. Objects exposed to the sun rise to very high temperatures; 150° is not uncommon and 200° has been reached. These regions are rather dry and dusty in summer but generally have sufficient water for agriculture, either from winter rains or from irrigation. The high day temperatures cause trouble with any materials which soften with heat, such as photographic films, confectionery, electrical insulation, etc., and these troubles are aggravated by condensation at night, due to the very large daily range of temperature, and this causes powdered products to cake. These regions are often subject to strong winds carrying much fine penetrating dust. Activity is impossible during the hottest part of the day, and there is risk

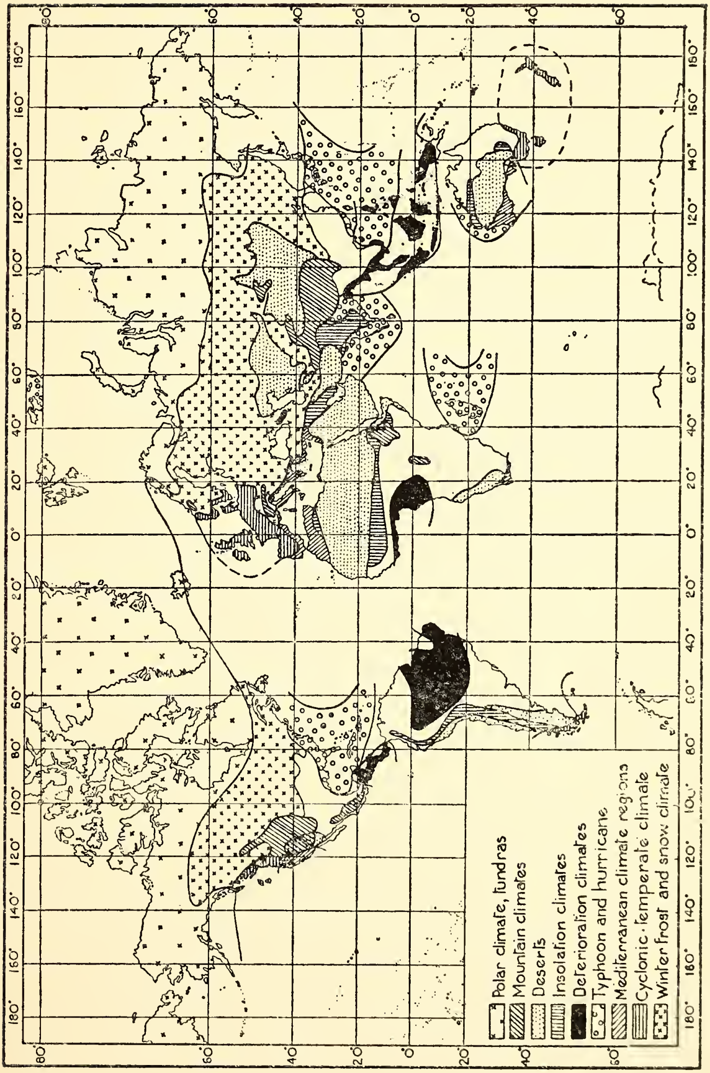


Fig. 1—Types of climate.

of heat stroke. In spite of all these disadvantages they are often economically important, owing to the high crop yields under irrigation. Egypt is the outstanding example.

(5) Deterioration climates. These are regions of high humidity combined with steady high temperatures which, however, are not extreme. Metals corrode rapidly and leather goods, clothes, paper, etc., soon go mouldy. The native populations lack energy and initiative, and white immigrants cannot maintain their efficiency for many years without occasional recourse to a cooler, more stimulating climate. Tropical diseases are rampant unless special precautions are taken against them. Vegetation grows abundantly; and this zone includes the dense equatorial forests of Brazil and the Congo. Where the forests have been mastered these regions are of very great importance for the supply of tropical agricultural products.

(6) Typhoon and tornado climates. These are regions, such as the West Indies, south-eastern U.S.A., parts of the coast of India and China and sub-equatorial islands, like the Philippines, having climates which are on the whole favourable, but which are liable to destructive winds exceeding 120 m.p.h. Although the intervals between these catastrophes are generally many years long, the risk is always present, and permanent buildings must be specially built to withstand them.

(7) "Mediterranean" climates. These regions are very pleasant. The winter climate is ideal, but the summers are too hot for sustained energy. They are most extensive on the coasts of the Mediterranean Sea, whence they take their name, but they also occur in southern California and a few other parts of the world. They produce wine, olives and similar deep-rooted crops.

(8) Cyclonic-temperate climates. The main feature of these climates is their changeability. The passage of cyclonic depressions maintains a continuous series of rapid changes of temperature in all seasons, with cloud, rain and wind alternating with spells of fine bright weather. Rainfall is generally sufficient at all seasons; persistent extreme heat or cold is rare. The climate is very stimulating, and the peoples of these regions are the most energetic and progressive in the world. The main regions included are parts of western and eastern U.S.A. and Canada, north-west Europe, Japan, parts of Chile, south-

eastern Australia and New Zealand. The importance of these regions in the world's economy has been emphasised by Ellsworth Huntington (1924).

(9) Winter Frost and Snow Climates. These include the interiors of North America and Eurasia in the same latitudes as the cyclonic climates of the coasts. Their main characteristic is the long cold winter, in which the ground is snow-covered for some months. In hilly regions the snow may be a serious obstacle to transport, but over flat country deep snowfalls are not very frequent. Nevertheless, in all the colder parts of this region it is necessary to provide against these occasions either by strengthening the roofs or by increasing their pitch. Dwelling houses and factories need thick or insulated walls and double windows to keep out the cold, and some form of central heating is required. Summers are rather warm, with a moderate amount of rain.

Parts of Fig. 1 are left blank. These fall into none of the nine categories and show no special characteristics, either favourable or unfavourable. They mostly have a warm climate with pleasant, dry winters and a summer rainy season.

*Working Efficiency in different Climates.*—Climate affects industry in two ways: by raising or lowering the general efficiency of the workers, and by its effect on the actual processes of manufacture. The main climatic factors affecting general efficiency are temperature, humidity and wind. The human body has a normal temperature of 98° F., which is maintained against the loss of heat to the surrounding air by the "combustion" of food in the body. This combustion also provides the energy for all activity, both mental and physical. Mental activity uses up comparatively small amounts of energy, but hard physical work uses up a great deal. In the process the body generates heat, which has to be dissipated to enable the body to maintain its normal temperature. Excess of production over dissipation of heat results in a rise of body temperature, which causes dizziness, a sense of depression, lassitude, and if it goes too far ends in cramps and heat-stroke.

Heat is dissipated in two ways, first by conduction and radiation, and secondly by evaporation. Conduction depends on the temperature of the air and the wind speed, and on the amount of clothing worn. Radiation depends on the temperature of the surrounding objects, which in a room means the

walls, ceiling and floor. A lightly clad office worker in a room in which the air is moist and free from draughts is most comfortable in a temperature of 60–65° F., *i.e.* the temperature at which the heat produced by the normal bodily activity just balances that lost by conduction and radiation. The introduction of appreciable air movement, such as by opening a window, even if the outdoor temperature is the same, causes a feeling of chilliness because the rate of conduction is increased. When the air temperature is above 98° F. the effect of conduction is to add heat to the body instead of removing it, and this effect is greater the stronger the wind. Strong winds at very high temperatures, such as occur in desert storms, may add to the body more heat than it can dispose of by other means. The result is rising body temperature, ending in coma and death. Similarly, exposure to strong sunshine may cause the gain of heat by radiation to exceed the loss, and to counterbalance that the loss of heat by conduction must be increased, either by lowering the temperature of the air or by increasing the ventilation. If the solar radiation cannot be compensated in this way heat-stroke results.

Heat-stroke is naturally most frequent in the tropics, both in regions of very high temperature such as the Punjab, Sind and North-west Provinces of India, Iraq and the dry, hot parts of Africa and Australia, and in places of damp heat such as the Persian Gulf, the west coast of Africa, Burma and Malaya. Heat-stroke also occurs, however, in "temperate" regions during abnormally hot summers, especially in the northern United States and even in Canada and Europe. Some people are more liable to heat-stroke than others; this can be determined by simple tests.

The loss of heat by evaporation depends on the amount of moisture in the air. Even when the body is cool there is always some evaporation in breathing, which is made visible in steaming breath in frosty weather. Since the air coming from the lungs is warmed to body temperature and saturated, there is always some loss of heat by evaporation in this way, the amount depending on the temperature and humidity of the air.

When, owing to high air temperature, sunshine, heavy manual work or other causes the body produces more heat than can be disposed of by conduction, radiation and evaporation from the lungs, the sweat mechanism comes into operation.

The body becomes wet, and so long as the air is not saturated and can reach the body, active evaporation takes place. Under similar conditions of clothing the rate of evaporation depends entirely on the wind speed and the saturation deficit, or the difference between the amount of water vapour in the air before it reaches the skin and the amount which it can hold. If the air is dry, evaporation goes on briskly and the body temperature remains normal. But if the air is hot and nearly saturated it cannot evaporate water so well, and consequently its cooling power is small or even zero. Under such conditions continual heavy work becomes impossible. A rough upper limit of comfortable conditions when the wind speed is small is given by the following table:—

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Temperature, ° F. . | 68 | 70 | 75 | 80 | 85 | 90 | 95 |
| Humidity per cent. | 80 | 77 | 69 | 58 | 46 | 35 | 25 |

Above these limits the conditions are "sultry" at the higher humidities and hot and irritating at the lower humidities.

A good measure of the cooling power of the air by conduction and evaporation combined is given by the wet-bulb thermometer. This is an ordinary thermometer in which the bulb is covered by a layer of muslin kept moist by a wick dipping into a container of distilled water. When the air is saturated there is no evaporation and the thermometer gives the air temperature. When the air is not saturated evaporation depresses the temperature of the wet-bulb below the air temperature, and the difference is a measure of the dryness of the air.

Hard physical work even with light clothing becomes very difficult when the wet-bulb temperature rises above 85° F., and is practically impossible with a wet-bulb above 90° F. Light work is possible up to a wet-bulb of 88° F. in still air or 93° F. in a moderate breeze; 78° F. has been taken as the limit for white settlers in the open, but experience during the war has shown that this limit is too low. For half-naked men the limit can be raised by 1-2° F. Figs. 2 and 3 show the average air temperature at sea level in January and July, and Figs. 4 and 5 show the average wet-bulb temperatures (approximate) in the same months over the land areas, not reduced to sea-level.

The air temperature at any height can be found approximately by subtracting from the sea-level value an amount of

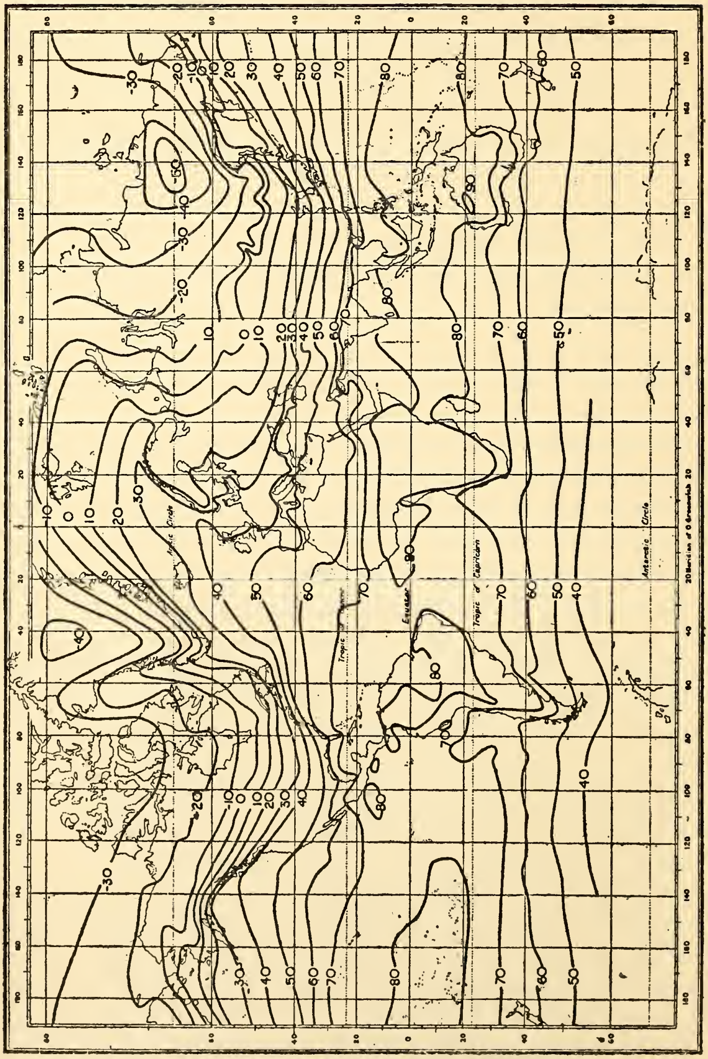


Fig. 2.—Average temperature distribution, January.

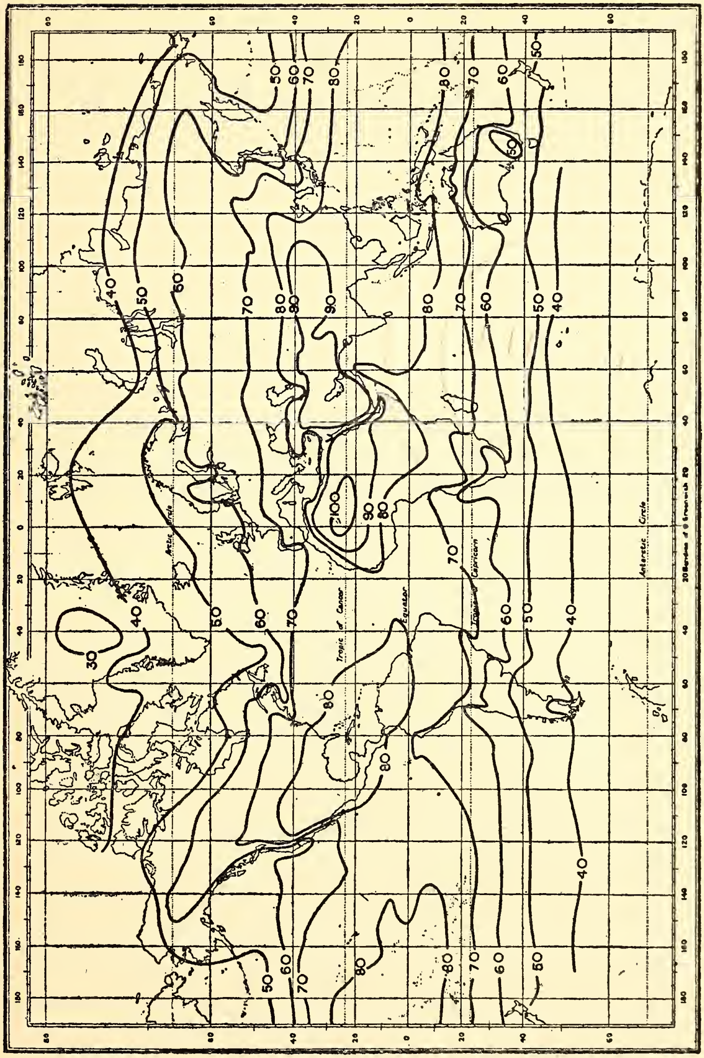


Fig. 3.—Average temperature distribution, July.

3° F. per thousand feet of altitude. For wet-bulb temperatures this relation does not hold; they decrease more slowly at high than at low temperatures. Below 32° F. the wet-bulb differs very little from the dry-bulb temperature.

The maps of mean wet-bulb temperature (Figs. 4 and 5) are based on the mean air temperature and mean relative humidity for the twenty-four hours at about a thousand well-distributed stations. The mean wet-bulb calculated in this way is slightly higher than that calculated directly from hourly readings of the wet-bulb thermometer, but some experiments showed that the error is small—rarely as much as 1° F.—and the maps can be accepted as substantially accurate except in regions of rugged topography, where it was impossible to show the effect of relief. The diurnal variation of wet-bulb temperature is much smaller than that of the air temperature, especially in hot regions, and is generally about 6° F. in middle and low latitudes. Consequently the wet-bulb during the hottest hours of the day can be estimated by adding 3° F. to the reading on the chart. Since a wet-bulb temperature of 78° F. is often quoted as about the limit for permanent settlement by whites, the wet-bulb isotherm of 75° F. is an important climatic boundary, and this is shown by a heavy line.

In January the isotherms of 75° F. include only two regions along the Equator, one from Brazil to the Guinea Coast of Africa, and the other from East Africa across the Indian and Pacific Oceans to about 155° E., including northern Australia. In this month the wet-bulb temperature nowhere exceeds 80° F. In July there are several small areas above 75° F. between the Gulf Coast of U.S.A. and northern Brazil, two small areas in West Africa, one over the Red Sea, and a long stretch from the Persian Gulf across India, Indo-China and southern China to 155° E., which includes two small areas with a wet-bulb above 80° F. There are two "islands" below 75° F. over the high ground in the interior of India and Indo-China.

With a mean wet-bulb above 70° F. conditions are likely to be uncomfortable on some afternoons. The most comfortable conditions for Europeans will be found between the wet-bulb isotherms of 50° and 60° F.

Although the effect of topography in mountain regions could not be shown on the maps, the lower wet-bulb temperatures at

high levels in the tropics are important for health stations. A few figures are given below:—

Table 1.—Variation of wet-bulb temperature with height.

| | *Height* | *Shade Temperature* | | *Mean Wet-Bulb* | |
|---|---|---|---|---|---|
| | feet | Jan. ° F. | July ° F. | Jan. ° F. | July ° F. |
| *India*— | | | | | |
| Lahore | 702 | 55 | 90 | 49 | 80 |
| Simla | 7,283 | 40 | 65 | 35 | 62 |
| *Ceylon*— | | | | | |
| Colombo | 24 | 79 | 81 | 79 | 77 |
| Diyatalawa | 4,101 | 65 | 70 | 62 | 63 |
| Nuwara Eliya | 6,170 | 57 | 60 | 54 | 58 |
| *Malaya*— | | | | | |
| Bukit Mertajam | 65 | 80 | 81 | 74 | 76 |
| Cameron Highlands | 5,120 | 64 | 65 | 61 | 62 |
| Gunong Tahan | 5,460 | 60 | 64 | 58 | 60 |
| *Java*— | | | | | |
| Batavia | 26 | 78 | 79 | 75 | 74 |
| Tosari | 5,677 | 62 | 59 | 59 | 56 |
| *Switzerland*— | | | | | |
| Zurich | 1,617 | 32 | 64 | 30 | 59 |
| Davos | 5,118 | 19 | 54 | 18 | 51 |
| Säntis | 8,200 | 17 | 42 | 15 | 40 |

The highest wet-bulb temperatures probably occur in the Red Sea and Sierra Leone areas, in both of which reliable readings have been known to exceed 90° F. Readings of 100° F. have been quoted, but are doubtful. In Britain a wet-bulb temperature of 70° F. may be expected once in two years; the highest reading in thirty-four years was 76° F.

A more exact measure of the cooling power of the air in different circumstances is given by Dr. Leonard Hill's "katathermometer." The bulb is dipped in hot water at a temperature of just over 100° F. and the time taken for its temperature to fall from 100 to 95° F. is measured. This is divided by a factor supplied by the manufacturer to give the cooling power of the air. The effect of clothing can be simulated by slipping a wet muslin glove over the bulb. This instrument is suitable for comparing conditions in different parts of a factory, but the readings are very local, and even if the observations were available they could not be made the basis of a world map.

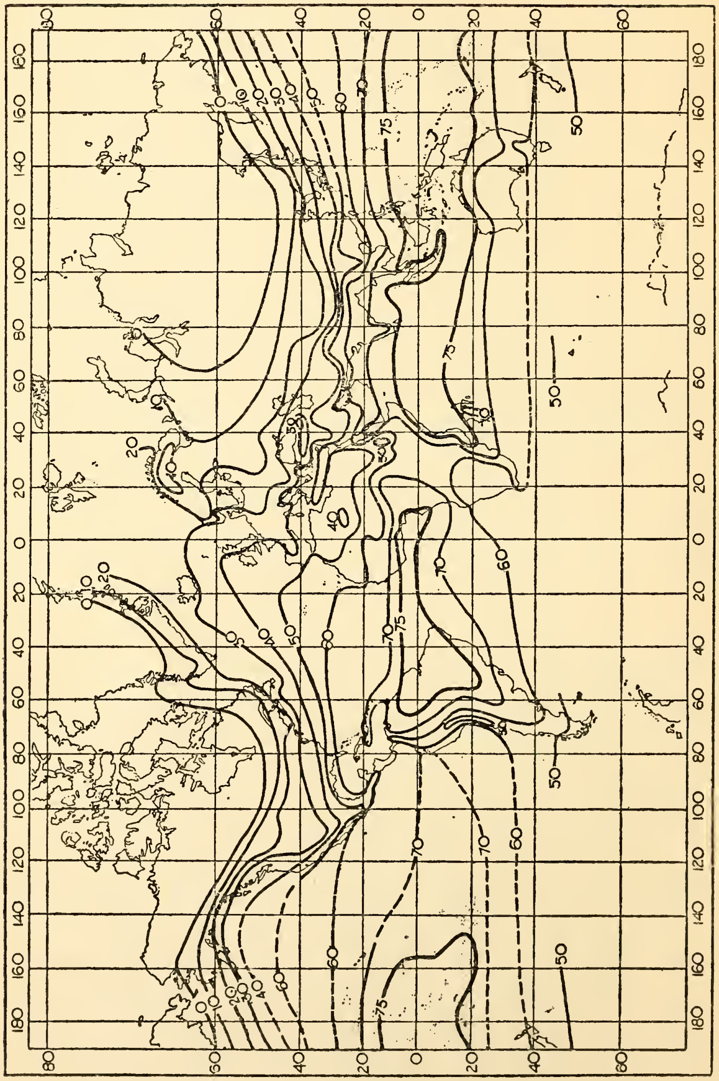

Fig. 4.—Mean wet-bulb temperature, January.

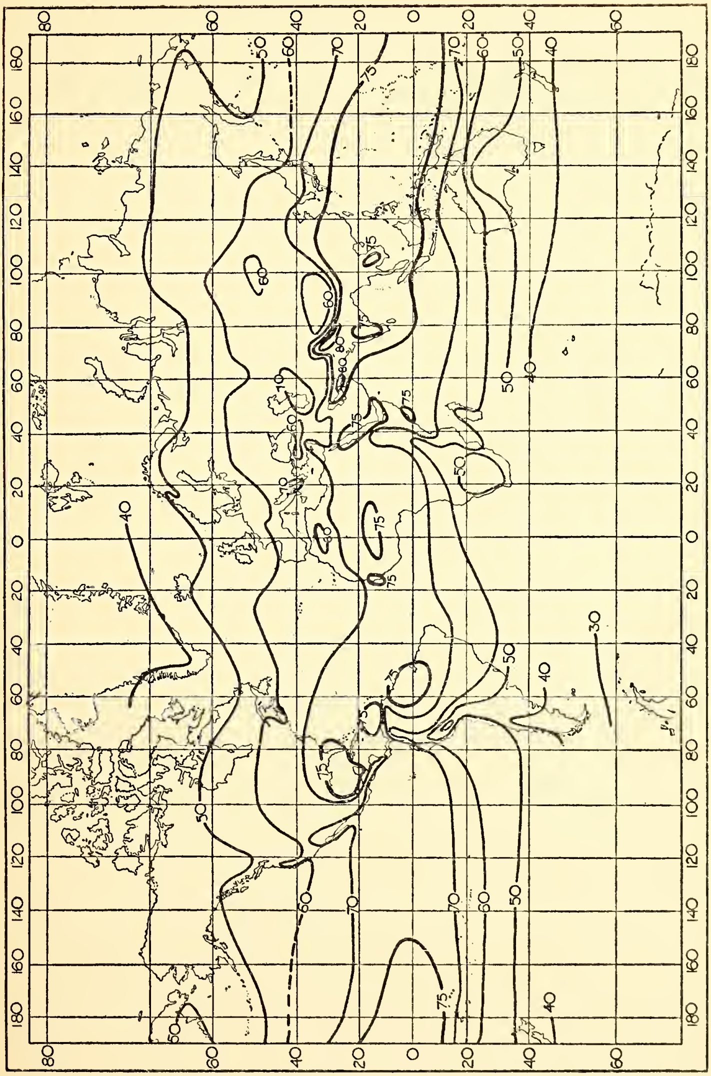

Fig. 5.—Mean wet-bulb temperature, July.

When the air temperature is very high and the air very dry, as happens in sub-tropical climates in summer, the amount of evaporation is very great. The body sweats profusely in the attempt to keep cool, and this loss of moisture has to be made good by drinking an equivalent quantity of fluid. Since the sweat contains salts, these also have to be replaced, and the best drink is slightly salted water. Drinking only plain water is liable to cause cramp. The stomach can only absorb a little under two quarts of water an hour, and cooling by sweating cannot for long exceed that produced by the evaporation of this quantity of water.

In offices and factories the effect of high temperature and humidity is accentuated by the heat and moisture produced by the workers themselves. Ventilation is only a partial remedy, for under extreme conditions the current of air required to give sufficient cooling would be so strong that it would raise dust and cause other inconveniences. The cooling power of the air increases only as the square root of the air speed, whereas the lifting of dust increases as the square of the speed. Air currents exceeding 500 feet per minute are impracticable for this reason. Under such conditions the only remedy is air conditioning.

This limitation of the amount of possible physical work by the cooling power of the air is only one of the reasons why the output of manual workers in the tropics is less than in cooler regions. The other reason is the monotony of the climate. Tropical uplands may have an ideal temperature and humidity for comfort, but if the weather is the same day after day, efficiency falls off and is replaced by boredom and lassitude. Moreover, the body loses its power of resistance to small changes of temperature and becomes subject to chills. The best climate for efficiency is one in which there is continual variety—spells of fine weather interrupted by the passage of storms, with corresponding changes of temperature and humidity. The best climate for all-round activity, physical and mental, is found in western Europe, the north-eastern United States and neighbouring parts of Canada, the coast of California, south-east Australia, Tasmania and New Zealand. Probably south-east England has the finest climate in the world from this point of view. Too much storminess goes to the other extreme, monotony resulting from the absence of relief by fine spells; continuous cloudiness is as depressing as continuous hot weather. The

whole temperate region between latitudes 30° and 60° is moderately favourable, except in the far interior of Asia. The Arctic regions are unfavourable because of the numbing effects of extreme winter cold, man's whole energy being taken up in keeping warm. Monsoon countries such as India and China gain from the marked alternation between the seasons, the dry, cool winter helping the inhabitants to carry on through the hot season, while the summer rains again bring relief. Even in countries most favoured climatically there are sometimes long periods of drought and high temperature, and these have been found to be associated with periods of industrial depression.

The loss of efficiency caused by climate can be minimised in various ways, such as the siting of houses and factories to take advantage of prevailing winds (Chapter II) or by air conditioning (Chapter XI). But apart from that, much can be done to provide amenities. Regular physical exercise at a suitable time of day (*not* the hottest part) is a partial substitute for variability of climate in maintaining efficiency, and mental variety is also helpful. In hot climates subject to much strong sunshine, loose white clothing is desirable.

After some time in a different climate the body tends to become acclimatised, especially after migrating from a cooler to a warmer climate, when the problem is that of disposing more readily of surplus heat. Migrants from a warmer to a cooler climate on the other hand have to produce more heat to counterbalance the increased loss, and this causes exhaustion and greater liability to disease. For this reason it may not be economical to import labour from lower latitudes.

### SUITABILITY OF CLIMATE FOR SPECIAL INDUSTRIES

It is well known that some manufacturing processes require special meteorological conditions, especially of temperature and humidity. The cotton industry, for example, requires rather moist air at a moderate equable temperature if the threads are to adhere properly. The most favourable conditions for spinning are said to be a temperature of 70–75° F. and a relative humidity of 65 per cent.; for weaving the best humidity is about 75 per cent. The moist, equable climate of Lancashire provides favourable conditions, and this helps to account for the early development of the cotton industry there. Spinning and weaving

of wool requires a lower humidity, about 60–70 per cent., and this industry grew up in Yorkshire, on the drier side of England. Of course, geographical conditions also played a part, the port of Liverpool being favourably situated for trade with the cotton-growing regions of America. Spinning artificial silk is also said to require a high humidity.

The manufacture of cigars and cigarettes requires only average conditions, but their conditioning calls for high temperature, around 90° F., and very moist air. At the other extreme is the manufacture of confectionery, which needs cool, dry rooms around 60° F. and a humidity of about 50 per cent. These and, in fact, all edible products also need clean air, free from dirt and pollution.

These are only a few examples selected at random; modern manufacturing processes are so complex that from start to finish a wide range of conditions is generally called for, and these can only be provided artificially. Moreover, the theoretically best conditions for the product may not be conducive to sustained output by the workers. In such cases a compromise is necessary. Generally speaking, a suitable outdoor climate and surroundings, with their good effect on the energy and efficiency of the workers, are more important than the requirements of the process rooms, since conditions in the latter can, within limits, be adjusted by air conditioning. The question of humidity in textile factories is especially important because the high humidity required for good products is very unfavourable to the welfare of the workers. Strict control is necessary and the conditioned air must be evenly distributed through the factory by proper circulation. Chen-li (1938), after investigating conditions in a cotton mill in China, advised that a better regulated humidification might double the efficiency of the weavers.

## POWER

There are two important sources of power which depend directly on meteorological elements, namely wind and water; a third possible source is solar heat.

*Water power.*—Running water has been used since very early times as a small local source of power to drive water-mills, the economic value of which was recognised in surveys such as Domesday. The use of water power in early times was, how-

ever, rather inefficient, and was limited by the fact that the natural conditions which are most suitable—rugged topography and rapidly flowing rivers—are not those which favour agriculture. The development of hydro-electricity, by enabling power to be transmitted to a distance, has removed this limitation.

The value of a river as a source of power depends on three factors, the volume of water, the reliability of the flow, and the slope of the valley, especially the presence of waterfalls. The volume of water depends on the area of the gathering ground, the depth of the rainfall, and the proportion of the latter which reaches the river. One inch of rain over a square mile is equal to 2,323,000 cubic feet of water, but the losses by evaporation, transpiration and deep percolation may account for anything from one-tenth to the whole of this. Rainfall is greatest on high ground, and in mountain areas the proportion of run-off to rainfall is generally greatest, hence in many respects mountain districts provide the most favourable opportunities for developing hydro-electric power.

Reliability of rainfall depends on four factors: the way in which the fall is distributed through the year, the variability of the fall from year to year, the size of the gathering ground, and the storage of water in the sub-soil and in swamps and lakes. The variability of rainfall both through the year and from year to year is least in the rainier parts of the cyclonic-temperate regions, particularly in those countries where high ground fronts prevailing winds blowing off the sea. These regions have large annual averages of rainfall, so that there is plenty of water at all seasons. On the other hand, the gathering grounds are often small, since the rivers flow direct to the sea. Both lakes and waterfalls are most frequent in mountain districts which formerly bore glaciers, such as Scotland, Wales, Norway, the Alps and much of northern North America, and these mostly coincide with the "cyclonic temperate" climate. Where lakes and waterfalls are absent, it is necessary to construct artificial ones by building dams.

The least favourable type of climate for hydro-electric works is, apart from deserts, the "Mediterranean" type, with its long, dry summer, in which the rivers fall to very low levels before they are replenished by the winter rains. Very cold climates are also not suitable, because the rivers freeze in winter.

Monsoon climates are somewhat better because the dry season comes in winter when evaporation is least.

Rugged topography is necessary to provide a head of water to drive the turbines. The most favourable site is naturally a high waterfall in a large, steady river. The combination of a large river, high falls and the "Great Lakes" to equalise the flow, all in a locality suitable for extensive industry, makes the Niagara Falls highly favourable for the development of hydro-electric power on a very large scale. Other suitable regions are the Victoria Falls on the Zambesi, and the Nile where it issues from Lakes Victoria and Albert, but these African sites are all distant from industrial centres and the power will have to be transmitted over long distances. Small mountain valleys, such as those of western North America, cannot provide power on the same scale, but are useful as cheap local sources.

*Wind power.*—Wind may be used as a source of power for pumping, generation of electricity, etc., as well as for ventilation and removal of noxious fumes. In most countries the variability of wind speed is too great for wind to be used as a source of power without either expensive storage batteries or an alternative source of power; hence it may not be economical.

The power yield is proportional to the cube of the wind speed, so that with a wind of 30 m.p.h. it is twenty-seven times the yield at 10 m.p.h. At low speeds the yield is negligible, and modern wind generators do not become effective until the speed rises to about 8 m.p.h. On the other hand, the wind pressure on the sails becomes dangerous when the speed exceeds 30 m.p.h., and they are designed to turn into the wind and go out of action at about this speed. Hence the useful range of wind speed is between 8 and 30 m.p.h. (in India, where the winds are generally lighter than in Britain, the type of wind generator advocated becomes effective at 6 m.p.h., but has a correspondingly lower maximum; in the U.S.A. the effective minimum is regarded as 10 m.p.h.).

The average wind velocity increases with height above the ground. The rate of increase depends on the nature of the surface, being least above water surfaces or smooth grassland, and greatest above broken irregular ground or surfaces broken up by buildings. It is also greatest at night and in cold weather, and least on hot sunny afternoons. As a general average in temperate regions we may use the following table, which gives

the speed at any height as a ratio to that at 33 feet (10 metres). This is the standard height of anemometers at meteorological stations from which most official statistics are derived.

TABLE 2.—Variation of wind with height.

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Height (feet) . . | 5 | 10 | 15 | 20 | 30 | 40 | 50 | 60 | 100 | 150 | 200 | 300 |
| Ratio to 33 feet . . | ·73 | ·81 | ·875 | ·92 | ·99 | 1·03 | 1·07 | 1·1 | 1·21 | 1·29 | 1·35 | 1·46 |

The power developed varies somewhat with the type of windmill. A trial French integrator was graded to give $0{\cdot}37\ (V/10)^3$ kilowatts per square metre of sail surface, V being the average wind velocity in metres per second. When V is expressed in miles per hour this is equivalent to $0{\cdot}31\ (V/10)^3$ kw. per 100 square feet of sail surface. The actual yield would probably be slightly less than this.

Since the power developed is proportional to the cube of the wind speed, and the latter is roughly proportional to the fifth root of the height above the ground, the effectiveness of a generator is more or less proportional to the square root of the height of the sails above the ground. The increase of effectiveness is probably greater than this, however, almost linear, because the gustiness of the wind decreases with height. The most favourable site is on the crest of a long, high ridge lying across the direction of the prevailing wind. Between 100 and 200 feet above the crest the wind speed exceeds that at the same level in the free air above level country, the acceleration factor being the greater, the higher and steeper the ridge. A windward slope of 1 in 10 increases the wind speed over the summit by up to 15 per cent., of 1 in 7 by up to 23 per cent., and of 1 in 4 by up to 35 per cent. Sites over very steep slopes are unfavourable because the wind is thrown up nearly vertically and becomes very turbulent.

A high average wind speed is not necessarily an advantage however. Owing to the variability of speed there are times when the speed is so high that the windmill shuts down, and other times when it is below the effective limit. With increasing average speed the duration of winds below, say, 8 m.p.h. decreases, and that of winds above, say, 30 m.p.h. increases, but the two changes do not cancel out. The net result is that, with winds of average steadiness such as are found in the British Isles, the duration of winds between 8 and 30 m.p.h. is greatest where the average wind speed is between 14 and 18 m.p.h.

The variation of effective duration with average wind speed is shown by the full curve of Fig. 6, which was calculated by a method devised by C. E. P. Brooks (1949).

Table 3 gives for a few places the percentage time during which the observed wind was between 8 and 30 m.p.h. at 33 feet, and the estimated time at 100 feet, for the year as a whole and in winter and summer.

TABLE 3.—Percentage of time with winds between 8 and 30 m.p.h.

| | Lat. N. | Long. | Height feet | Mean Speed m.p.h. | 33 feet | | | 100 feet | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Winter | Summer | Year | Winter | Summer | Year |
| Tiree (W. Scotland) | 56 32 | 6 55 W. | 75 | 15·9 | 68 | 67 | 70 | 62 | 70 | 66 |
| Abbotsinch | 55 52 | 4 26 W. | 65 | 8·3 | 44 | 40 | 44 | 50 | 52 | 51 |
| Cranwell | 53 22 | 1 37 W. | 284 | 10·3 | 68 | 61 | 54 | 67 | 68 | 69 |
| Felixstowe | 51 58 | 0 7 E. | 60 | 11·2 | 65 | 59 | 61 | 68 | 66 | 67 |
| Croydon | 51 21 | 0 7 W. | 313 | 11·0 | 61 | 46 | 53 | 67 | 58 | 62 |
| Calshot | 50 49 | 1 18 W. | 58 | 12·9 | 71 | 65 | 68 | 73 | 73 | 72 |
| Boscombe Down | 51 10 | 1 45 W. | 462 | 10·0 | 64 | 44 | 64 | 68 | 53 | 61 |
| Manchester (Barton) | 53 28 | 2 23 W. | 153 | 9·1 | 60 | 46 | 53 | 64 | 55 | 60 |
| Aldergrove (N. Ireland) | 54 39 | 6 13 W. | 328 | 10·0 | 60 | 48 | 54 | 66 | 59 | 63 |
| Harpenden | 51 49 | 0 21 W. | — | 9·0 | 61 | 25 | 49 | 65 | 34 | 58 |
| Perpignan | 42 41 | 2 55 E. | — | 14·6 | — | — | 41 | — | — | 38 |
| Brest | 48 25 | 4 30 W. | — | 15·8 | — | — | 76 | — | — | 72 |

The first nine places are from averages for several years compiled by the Meteorological Office, London. The figures for Harpenden are for one year only, based on a Bulletin of the Institution of Agricultural Engineering, Oxford (1926). The figures for Perpignan and Brest are read off a diagram by P. Ailleret (1946).

As the power yield is proportional to the cube of the wind speed, the greater part of the power is given by winds near the upper working limit, *i.e.* between 25 and 30 m.p.h. These are more frequent with high than with low average speeds. The power yield of a windmill operating between 8 and 30 m.p.h. for different average speeds is shown by the broken curve of

Fig. 6, which indicates that the greatest power yield is given by an average speed of about 20 m.p.h. The scale on the right gives the power yield as a percentage of that of a windmill running full time at 30 m.p.h. Since reliability is desirable as well as maximum yield over short periods, the optimum average wind speed is probably about 18 m.p.h. This is very little above the average wind speed at 33 feet in the

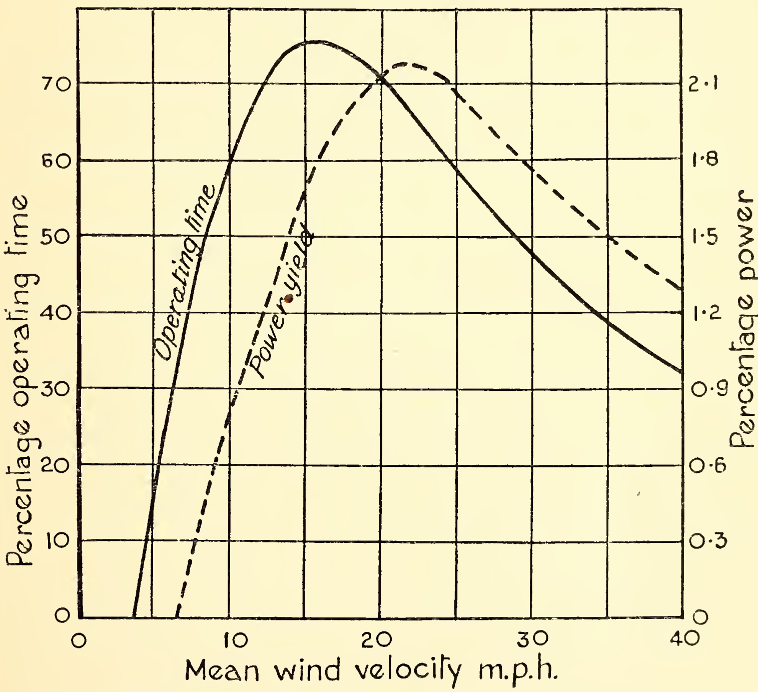


Fig. 6.—Operating time and power yield of a windmill at different mean wind speeds.

windiest parts of Britain, and in such places there would be little advantage in seeking greater wind speeds either by raising the sails to great heights above the ground or by going to the windiest ridges. Inland, however, where the average wind speed is much less than on the western coasts, a lofty installation would be an advantage.

At places where the wind is steady, such as islands in the Trade winds, the curves of Fig. 6 are much steeper, so that if the average wind speed is between 15 and 20 m.p.h. a windmill

operating between 8 and 30 m.p.h. will rarely be idle. If the average wind speed is below about 12 m.p.h. a windmill operating between lower limits of wind speed would be more reliable.

*The Use of Solar heat as a source of power.*—The suggestion has often been made that the heat of the sun's rays could be used as a source of power to work a heat engine. It is possible that in a sub-tropical country with almost continuously clear skies, such as Egypt, this source of power might be economical, but in general the yield of power is low for the area of plant required, and it is doubtful whether, even in the most favourable circumstances, the value of the yield expressed as a percentage of the cost of installation can compare with the cost of other sources of power. A discussion of the possibilities is given by H. C. Hottel (1941) and F. Trombe (1948).

## WATER SUPPLY

Most large towns have a reasonably well-assured supply of water. Where much water is used, and has to be obtained from local sources, the possibility of drought has to be considered. The practice of water engineers in Britain is to provide sufficient storage to ensure the water supply against the three driest consecutive years to be expected in an average period of fifty years.

The sources of water supply may be divided into rainfall; wells and springs; rivers, lakes and reservoirs.

(1) *Rainfall.*—In this country few areas depend solely on the artificial storage of rainfall, but in other parts of the world this may be the only source of supply. Even in Britain rain may serve as an auxiliary source, or for processes for which soft water is essential. The gathering ground consists of the roofs of all the buildings, whence the water is led by pipes and gutters into covered cisterns. When the cisterns are full any further rain is not available for use. Hence there are two problems to be faced: first, the provision of sufficient storage capacity to tide over the longest dry period to be expected; secondly, the provision of a sufficient gathering area to keep the cisterns full during periods of rain.

The period of drought to be provided against must be calculated from records of daily rainfall at the site or at some neighbouring comparable place. These records can be obtained from the official weather service of the country concerned, or

through the British Meteorological Office. For this purpose drought must be defined, not as the period entirely without rain, but as that between the last fall sufficient to top-up the cisterns to capacity and the first fall sufficient to wet the roofs and leave something over. It must be remembered that the whole of the rain does not reach the cisterns; some is evaporated from the roofs, the amount lost being greater if the roofs are covered by slightly pervious tiles than from impervious slates

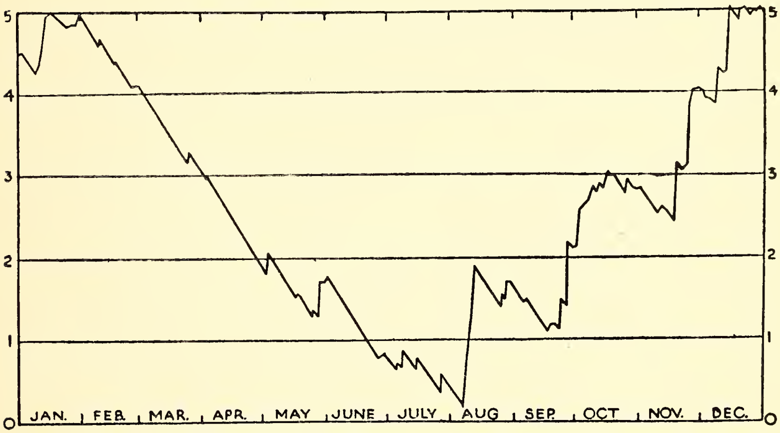


Fig. 7.—Level of a rain-storage tank, London, 1938.

or galvanised iron. An allowance of 10 per cent. should be made for this loss.

In regions with an uncertain rainfall or with a long, dry season, provision against drought will be the governing factor; in wetter regions with a more regular rainfall the daily requirement. The safest procedure is to select from the records the driest year and plot the water-level in the cistern day by day. Suppose that the requirement averages $X$ gallons a day, which is equivalent to a rainfall of $x$ inches on the roof-space available; $x$ might be, say, 0·04. We will also suppose that on each rain-day the first 0·01 inch in winter and the first 0·02 inch in summer is lost by evaporation from the roofs and gutters without reaching the cisterns. Let the capacity of the cistern be $Y$ gallons, equivalent to a rainfall of $y$ inches; $y$ might be 5·0 (three months' supply). We can then proceed to calculate the level of water in the cistern day by day.

An example is shown in Fig. 7, which represents the variation

of level of a cistern under these conditions in London during the dry year 1938. Since we are starting in winter, when the rainfall is generally sufficient, we will start with the cistern at a level equivalent to a rainfall of 4·5 inches. 1st January was dry, so the level drops to 4·46. On 2nd January the rainfall was 0·08 inch, so the level rises by 0·08 inch less 0·01 inch evaporation and 0·04 inch consumption, *i.e.* by 0·03 inch to 4·49 inches. After some fluctuations the level reaches 5 inches, and any further rainfall runs to waste. During the dry spring and summer the level falls steadily and by 6th August it is down to 0·18 inch, which is definitely in the danger zone, but after that wetter weather sets in and by mid-December the cistern is full.

Allowing for a 10 per cent. loss, each gallon of water a day requires about 800/R square feet (horizontal projection) of roof, where R is the lowest twelve-monthly rainfall to be expected. In London, for example, the rainfall in twelve consecutive months is not likely to fall below 11 inches, so that a daily requirement of 100 gallons would be assured by a horizontal roof area of 7,300 square feet. Calculations along these lines will ensure against risk of water shortage, and may also avoid the expense of providing unnecessarily large storage.

(2) In *wells* and *springs* natural storage takes the place of artificial cisterns, and generally provides a greater reserve. The yield of large wells varies from a few hundred thousand to two million gallons a day. These natural sources draw their supplies from a larger area than roofs, but losses by evaporation and run-off are also greater. All the factors being uncertain, the question of reliability can only be determined by past records of yield or, if these are not available, by a geological survey.

Wells are generally most reliable on low ground near springs or streams, and least reliable on high ground. Since bulk storage of water from wells and springs is rarely practicable, the reliable yield is the actual minimum observed or calculated over a considerable period of years. It should also be remarked that the pumping of water from a well lowers the water-table in the rocks, and hence the yield of the well. Doubling the number of wells in a small area does not usually double the yield; in fact the increased supply may be quite small. According to H. Lapworth (1930), the effect of a large well on the water-table may extend to a distance of one or two miles; a well

in California was even shown to affect the water-table at a distance of 5 miles.

(3) *Rivers, lakes* and large *reservoirs* are the most reliable source of supply. Sufficient information as to the levels of rivers in past years is generally available to serve as a guide, but riparian rights have to be considered. The amount of water taken from a river must not be so great as to interfere with the users further downstream, and if the used water is returned to the river it will probably have to be purified first. Lakes and large reservoirs generally provide sufficient reserves to cover all reasonable vicissitudes, but they are liable to other troubles, such as silting or the growth of organisms.

The usual practice in estimating the reliability of a natural source of water dependent on rainfall is to take as a basis the smallest annual rainfall to be expected in three consecutive years during a period of fifty years, the losses being regarded as constant. In the British Isles this is usually taken as four-fifths of the average annual rainfall; it can be estimated more accurately from a comparatively short period of observations by statistical methods. If the average annual rainfall over a period of N years is R inches, the first step is to write down the difference between the rainfall of each individual year and the average R. These are added up, ignoring minus signs, and divided by the number of years N. This gives the *mean deviation* D, or the average amount by which the rainfall of any year differs from the average rainfall. Then the smallest rainfall to be expected in any one year out of fifty is less than R by about two and a half times D. The smallest rainfall to be expected out of fifty sets of three consecutive years each is less than three times the average annual rainfall by about four and a half times D, or, allowing for some persistence of drought from year to year, smallest three-year rainfall equals $3R-5D$.

The loss by evaporation is not constant from one year to the next, but varies with the rainfall and temperature. In dry summers the soil dries out and consequently the total loss by evaporation decreases with decreasing rainfall, but less rapidly. Evaporation increases with increasing temperature, by from 0·6 to 1 inch a year for each increase of mean annual temperature by 1° F. As, in Britain, rainy summers are generally cool, the two factors more or less cancel out and the observed loss by evaporation remains fairly steady at from 11 to 17 inches

a year, increasing from north to south (H. Lapworth, 1930). Evaporation is almost confined to the summer half-year, and in Britain rivers most often reach their lowest level of the year in September.

The disposal of waste water may be a serious problem. The subsoil is generally an excellent natural filter (apart from the presence of cracks), and in dry country with porous rocks a sump well away from the source of water supply is the best means of disposal. If the ground becomes waterlogged or frozen this is no longer practicable. Meteorological records will show the risk of frost. Waterlogging depends mainly on the nature of the subsoil and partly on the difference between the rainfall and evaporation at different seasons. The risk can best be diagnosed by the study of past records; levels of water in wells are useful for this purpose.

### TRANSPORT

The last aspect of the economics of climate to be mentioned is the possibility of interference of access by fog, snow, ice, floods and similar obstacles. Fog also adds to the cost of lighting. *Fog* consists of minute water droplets suspended in the air. It is most frequent in humid climates, especially where the rainfall is moderate. There are two types of fog: *radiation fog* and *advection fog*. Radiation fog occurs on low ground, especially broad, level river valleys, when the temperature falls owing to radiation on cold nights; it is caused by the air cooling below the dew point. Flat river valleys such as lower Thames and Lea valleys near London are especially liable to fog because the air is nearly but not quite stagnant and there is a good deal of water about to keep the air moist.

Advection fog is caused by the cooling of air blowing over a colder surface or by the mixture of two moist air currents at different temperatures. It is especially common where a cold current flows along a coast, as in California and north-eastern North America.

Fog is especially prevalent over large towns. This is partly because the chemical particles in the smoky air provide nuclei for the condensation of moisture, and partly because the smoke particles themselves decrease the visibility. Where country fog is white and clean, town fog is black and dirty. In addition to the London region, town fogs are very frequent

along the coastal regions of Belgium, Holland and north-west Germany.

Owing to the local nature of fog it is not possible to give a world map of its distribution. The official international definition of a fog is a horizontal visibility of less than 1,100 yards (1,000 metres), but some of the figures may refer to different criteria. Visibility of this range interferes with flying, but has little effect on land transport. "Thick fog," defined as visibility less than 220 yards, interferes with all forms of traffic; on the average it occurs on five or six days in each winter in London. In the United States before 1940, thick fog was defined as visibility less than 1,000 feet; with light fog it might be 6 miles or more. In the centre of large towns such as London the warmth of the town itself dissipates the fog at ground level, and a fog often takes the form of a dense overhead cloud not much above roof level, which produces the darkness of night in the streets. Lights have to be lit in all buildings, but visibility remains quite good at street level.

The worst fogs can generally be avoided by selecting a site on the lower hill slopes above the valleys, but not on the tops of the higher hills. In the London area, for example, there are two belts, one of radiation fog in the valleys and the other, which really consists of low cloud, on the hills above a height of 500–600 feet. Free air drainage is essential, and in consequence the least foggy situations in any district are also those most free from frost.

*Snow.*—Places in cold climates record anything up to 100 days with snow a year. Many of these are light falls which soon melt, but others are heavy falls, often accompanied by strong winds which pile up the snow in deep drifts and cause widespread interruption of road and rail transport. These include the famous "blizzards" of North America, but similar conditions also occur in this country and in Europe and Siberia. An account of these blizzards is given in Chapter X.

The best criterion of the effect of snow on human activities is the duration of the period of snow cover. A generalised map of the average duration on low ground is shown in Fig. 8. Over most of the area this is based on actual observations of snow cover; for Canada such records could not be found and the map was completed by using records of the average duration of the period with mean temperature below 32° F. and finding

the relation between the latter figure and the duration of snow cover in similar latitudes of northern Europe and Siberia. The average duration is less than a month over the western coast of North America south of about 55° N., over the United States south of about 38°, and over western and southern Europe. It increases rapidly northward and eastward and exceeds three months over most of Canada, the interior of Norway, Sweden north of Stockholm, Finland, the U.S.S.R. and the mountain regions of central Asia.

The scale of the map is too small to show the variations over the British Isles. Generally speaking the duration is less than 5 days a winter over the low ground near the western and southern coasts, 5–10 days over most of England and southern Scotland, 10–15 over moderately high ground (up to about 500 feet) in southern and central England and 15–20 over similar ground in north-east England, increasing rapidly at higher levels. From data given by G. Manley the duration in Scotland increases from about 10 days at sea-level to 82 at a height of 1,500 feet, an increase of 1 day for each 22 feet of height. From 1,500 feet to the summit of Ben Nevis (4,406 feet, duration 230 days) the increase is at the rate of 1 day for each 20 feet of height. In the Alps the duration of snow cover increases at the rate of about 1 day for every 33 feet of height. In the Pennines the increase is from about 15 at 350 feet to 76 at 1,840 feet, or 1 day for 24 feet of height.

Manley also gives the following data about the snow cover on some main roads:—

TABLE 4.—Snow on main roads, Britain.

| | |
|---|---|
| London–Edinburgh (A.68). Carter Bar, 1,300 feet | 53 days |
| London–Glasgow (A.6). Shap, above 1,300 feet | 40 ,, |
| Stainmore (A.66). 1,400 feet | 50 ,, |
| Manchester–Sheffield (A.57). "Snake" above 1,500 feet | 45 ,, |
| Perth–Braemar (A.93). Cairnwell, above 2,000 feet | 110–120 ,, |
| Perth–Inverness (A.9). Drumochter, 1,500 feet | 75 ,, |
| Glencoe Road (A.82). Rannoch Moor, 1,100 feet | 55 ,, |

The depth of the snow cover is so variable from year to year that in Britain at least average figures have no meaning. R. G. Stone (1940, 1944) gives figures for New England, from which the following table is a very brief excerpt.

Average consecutive number of *weeks* with 2 inches or

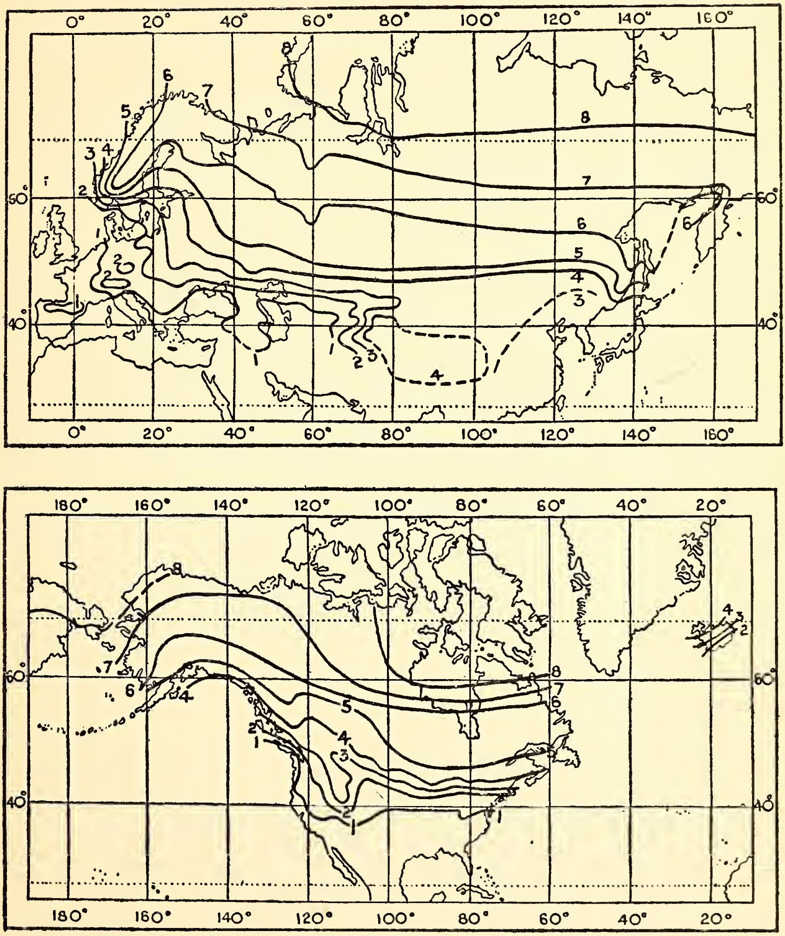

Fig. 8.—Number of months with snow-cover on low ground.

more, 5 inches or more, etc., of snow on the ground in New England.

TABLE 5.—Depth of snow, New England.

| | *2 inches or more* | *5 inches or more* | *10 inches or more* | *15 inches or more* |
|---|---|---|---|---|
| Low ground . . . | 5 | 0–5 | 0–4 | 0 |
| Moderate height (100–200 feet) . . . . . | 15 | 10 | 5 | under 5 |
| High ground (above 800 feet) | 20 | 15 | 10 | 5–10 |

The average depth in inches of snow at three places on various dates is:—

| | Height feet | Oct. | Nov. | | Dec. | | Jan. | | Feb. | | March | | April | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 31 | 15 | 30 | 15 | 31 | 15 | 31 | 15 | 28 | 15 | 31 | 15 | 30 |
| New York N.Y. (Battery Park) . | 5 | — | T. | 0·3 | 0·8 | 0·7 | 1·0 | 2·0 | 2·0 | 1·0 | 0·5 | — | — | — |
| Ithaca N.Y. . | 836 | — | T. | 0·2 | 0·3 | 0·3 | 2·0 | 3·0 | 4·0 | 3·0 | 2·0 | 1·0 | 0·2 | — |
| Bethlehem, New Haven . | 1440 | — | 2·0 | 3·0 | 5·0 | 7·0 | 9·0 | 12·0 | 15·0 | 15·0 | 13·0 | 5·0 | 0·8 | — |

It is necessary to distinguish between two types of snow cover. In countries with a long, cold winter, such as eastern Europe, northern Asia and the northern interior of North America, a snow cover forms early in the winter and persists throughout the season. The duration and depth vary considerably from year to year, and in the border regions there may be occasional thaws, but the general course of events recurs every year. The first snow soon becomes compacted and every further fall adds to it, to be compacted in turn. The falls are rarely heavy, the bulk being made up of frequent light falls. Blizzards occur, but these are due more to the raising of the surface snow by strong winds than to heavy fresh snow. This type of snow cover causes the minimum of interference to traffic; since it is expected, provision is made for it such as the substitution of sleighs for wheeled traffic. Winter is often the favourite season for travel, the frozen snow-covered rivers making excellent highways. Where the snow is heavy enough to block railways, as in the mountain region of Canada, protection is provided

in the form of snow sheds. The worst period comes in spring, when the snow melts and is replaced by slush, mud and often by floods; conditions are especially bad where the ice breaks up in the upper reaches of rivers flowing north, while the lower reaches are still frozen. This type of snow cover is roughly limited by the area within which at least one month has a mean temperature below 32° F., shown by the broken line in Fig. 8.

The second type of snow cover is intermittent. It occurs in cyclonic regions where winter temperature oscillates about 32° F. Falls of snow are much less frequent than in the colder regions, but when they occur they are often heavy, and are accompanied by strong winds which cause drifts. Later there is a thaw, which may be accompanied by heavy rain and bring severe flooding. This type of snow cover is very irregular in its occurrence; whole winters may pass without snow settling on the lower ground, while in others there may be repeated falls and snow may persist for many weeks. This type of cover causes great inconvenience; the deep snow does not have time to become compacted and the drifts block roads and railways, isolating country districts completely. In cities the roads are cleared by snow-ploughs. These snowstorms are best known in the north-eastern States of the U.S.A., especially in New York, but they also occur in Britain.

"*Glazed frosts*" or ice-storms occur occasionally in North America and Europe. They take two forms. In the first rain falls on frozen roads and similar surfaces, or on compacted snow, and freezes. The ice-cover does not often reach any great thickness or persist long, and this form is not a serious hindrance to traffic. In the second type the raindrops consist of water which is still liquid but below its freezing point (supercooled water). Each drop freezes immediately it strikes any solid object. Roads are covered by a sheet of hard, smooth ice which gives no grip, so that wheeled traffic is impossible and even walking very difficult. Telephone and telegraph wires become thickly coated with ice, which is so heavy in bad storms that the wires break under the strain, completing the interruption of communications. A severe glazed frost at the end of January 1940 paralysed large areas of southern England for several days, but occurrences on this scale are very rare, probably not oftener than once a century, and costly special precautions against them are not justified.

Glazed frosts are probably more frequent in the United States, where they are known as "ice-storms." They are especially frequent in the middle latitudes of the eastern United States; one of the worst examples occurred on 26th to 29th November 1921, in which wires were coated with cylinders of ice 3 inches in diameter. Telephone and telegraph wires, and even the posts carrying them, were brought down, the electric supply was interrupted and all forms of communication ceased. Orchards and even forest trees were destroyed, the total damage running into millions of dollars.

*Frost.*—Frost is not a direct hindrance to transport, but it has a cumulative effect on road surfaces. Ice crystals and layers of ice form beneath the surface and break it up. Damage from this cause is greater in gravel than in tarred or asphalted roads, which hinder the penetration of both water and cold. Wet ground freezes to a greater depth than dry ground, and the tar or asphalt layer has itself some insulating property. It is estimated that the damage caused by frost to the streets of Ohio by the severe winter of 1935–6 amounted to 3,000,000 dollars. It may be remarked that a snow cover is a good protection against damage by frost. Fresh snow, owing to the large amount of air which it contains, is the most effective, but even old compacted snow is a good insulator.

Frozen earth is also more elastic than unfrozen ground, and transmits the vibrations from heavy traffic to neighbouring buildings. For this reason it is a good plan to maintain a bed of well-worked loose soil, such as a garden, between buildings and neighbouring roads carrying heavy traffic.

*Interruption of Navigation by Sea Ice.*—The most serious effect of winter cold on transport is the blocking of rivers, harbours and coasts by floating ice. The areas chiefly affected are: (1) South-eastern Canada and the St. Lawrence Estuary; (2) Newfoundland, Labrador and Hudson Bay; (3) the White Sea and the Arctic coast of the U.S.S.R.; (4) the coasts of the Baltic; (5) the coasts and river mouths of the Black Sea; (6) the Sea of Okhotsk, and neighbouring coasts.

(1) The rivers of eastern North America and the landlocked harbours north of about latitude 45° freeze in winter, and in the smaller ports navigation is interrupted for two or three months. There is some freezing of rivers down to latitude 37° or 38°. The more important ports are generally kept open by

ice-breakers or by the normal traffic. Table 6 gives the average dates of closing and opening of a number of ports; fuller details are given in the *Ice Atlas of the Northern Hemisphere*, published by the Hydrographic Office, Washington, price eight dollars. In the ports which are blocked each winter the regular steamer services are usually withdrawn two or three weeks before the average date of freezing, and resumed a few weeks after the thaw. Lake Erie is heavily iced in January and February.

The narrow entrance to the St. Lawrence Estuary through Cabot Strait, between Cape Breton Island and Cape Ray in Newfoundland, is a great obstacle to shipping in winter. From about mid-January to late April drift ice makes the Strait impassable to ships not specially built to encounter ice. Towards the end of March the winter ice of the St. Lawrence River and the Great Lakes begins to break up, and from mid-April to mid-May there is a great rush of drift ice down the river. In many years Cabot Strait is jammed by ice, sometimes for as long as three weeks, between mid-April and mid-May, and completely closed to shipping. This ice-jam is known as the "Bridge"; it has caused a number of wrecks off the coast of Newfoundland.

(2) Newfoundland and Labrador. The river mouths and harbours of Newfoundland (except the south coast) and Labrador freeze for a time in winter; the average dates of closing and opening of ports are given in Table 6. A more serious obstacle on the east coast is the drift ice. During the winter Baffin Bay and all the western side of Davis Strait are filled with unnavigable ice until the end of June; this ice consists of floes in which icebergs are frozen. In the early spring this mass of ice drifts slowly south-eastwards in the Labrador Current, entering the Atlantic off Newfoundland. Here the ice-floes disintegrate in the warmer water, but the icebergs drift about off Newfoundland and sometimes penetrate far into the Atlantic, where they constitute a grave danger to shipping. On 14th April 1912 the s.s. *Titanic* struck a berg in lat. 41°46′ N., long. 50°14′ W., and sank with great loss of life. The amount and date of arrival of the ice vary greatly from year to year, but bergs frequently appear in numbers off the Newfoundland Banks in the second half of March.

Hudson Strait and Hudson Bay. Ice begins to form on the north shore of Hudson Strait and the shores of Hudson Bay in

October. Hudson Strait generally becomes unnavigable except by powerful ice-breakers in November, and in the same month fast ice has spread to all shores of Hudson Bay, though it is still thin in the southern half. The whole coast of Hudson Bay is blocked in December. The ice begins to break up in May and Hudson Strait is generally navigable by powerfully built vessels in June. In July all ice has practically disappeared. The Churchill and Nelson Rivers are closed to navigation from early in November to mid-May, and the Albany River from mid-November to early May.

(3) The White Sea and Arctic coast of Russia. Ice may form in the Gulfs of Kandalaksha, Onega and Archangel as early as October and regularly in November, but the northern part of the White Sea is not generally beset until December. The ice spreads westward along the coast until March, by which time it has generally reached Sviaitoi Nos; after this it retreats. The whole of the White Sea is covered by drift ice from January to April inclusive, but the central part is usually navigable by ordinary vessels in January and by heavily built ships from February to April. The ice becomes very loose in May and disappears in June. The Murman Coast is generally ice-free throughout the winter. The occurrences of ice are very irregular; in Table 6 the first and last dates over a period of about seventeen years are given.

(4) The Baltic. The western Baltic is not frozen regularly. In very severe winters ice forms in the estuaries south-west of Denmark, blocking Bremen and Hamburg, and somewhat more frequently farther east, but even ports as far east as Konigsberg are affected only one year in five. Entrance to the Baltic through the narrow straits of Denmark is only blocked in severe winters (not more than twice in ten years). The ice reaches its maximum thickness in February, and except in the severest winters the straits are clear by the end of March.

The coasts of the Gulf of Bothnia generally freeze in December or January. The southern half is freed about the end of April, but north of 64° N. the ice persists well into May. The ports from Umea round to Vaasa are closed every year, Hernosand one year in three and the Swedish coast between Hernosand and 60° N. only occasionally. Access to Stockholm is rarely hindered by ice, but ice sometimes blocks the narrow strait between Oland and Kalmar. On the

Finnish side Rauma is occasionally beset, but Abo (Turku) is not affected.

In the Gulf of Finland in average years ice appears on the north coast at the end of November, and by 11th December there is an even chance that the Bay of Kronstadt will be partly frozen. The limit of freezing in average years spreads gradually along the south coast during January and February, reaching its most westerly point, between 21° and 22° E., early in March. By this time the whole of the Gulf of Riga and the sea surrounding the islands of Hiiumea and Saaremaa is covered by unnavigable ice. From the beginning of April the ice breaks up rapidly, and the whole Gulf is generally free by the beginning of May. Viipuri and Kronstadt are closed every year, Helsinki about one year in two or three. Off south-west Finland navigation is not interrupted.

(5) Black Sea and Sea of Azov. Only the northern part of the Black Sea is affected by ice. The Lower Danube is frozen regularly, especially the delta round Galatz and Braila; the ice breaks up very rapidly at the end of February. In the north-west Black Sea all lagoons and river mouths are frozen regularly for a long period. On the south coast of the Crimea icing is slight, and the Strait of Kerch is not usually much affected until the end of January, when a wide belt of pack ice forms at the northern entrance. The Sea of Azov is the worst sufferer; ice-breakers keep the ports open during the first and last weeks of the ice season, but in the main cold period during February the ice is too thick.

(6) East Coast of Asia and Sea of Okhotsk. In the Yellow Sea ice occurs only in the bays on the west coast of Korea north of 37° N. in the second half of January and beginning of February; ice practically never appears in Korea Strait, and the Japan Sea proper is ice-free throughout the winter except for a narrow strip of drift ice from the Sea of Okhotsk lying off the Russian coast from Vladivostok northwards in January, February and the first half of March. Navigation is always possible south of 48° N. and Vladivostok is kept open by ice-breakers throughout the winter. On the east side of the Japan Sea there is little ice. The Gulf of Tartary, off Nikolaevsk, is blocked by compact ice by mid-December, and remains so until May or even early July.

In the Sea of Okhotsk ice formation begins at the end of

October or early November on the north shore; it persists until June, when in places it is only navigable by heavily built vessels, and some ice remains in July. Near the southern Kuriles drift-ice is met in March to May, but there is only scattered ice off the west coast of Kamschatka. Off eastern Kamschatka there is drift-ice and some fixed ice; access to Petropavlovsk is maintained by icebreaker. Farther north the Gulf of Anadyr is blocked from late November to early May, and Bering Strait from mid-October until late May.

The "*Debacle*."—The spring break-up of the ice in the rivers of Canada, Russia and Siberia is an imposing affair, which is termed the "Debacle." In southern Canada and southern Russia it begins about the middle of March, but is progressively later in higher latitudes, not coming until May or even June in the extreme north. It lasts from a fortnight to six weeks, during which time the drifting ice masses often form jams, blocking the rivers and causing floods. In the northward flowing rivers of Siberia, in which the upper courses melt first and flow over the still frozen lower reaches, the whole country becomes impassable; Irkutsk, for example, is isolated for a month in May.

TABLE 6.—Dates of Closing and Opening of Ports, etc.

| Place | Lat. N. | Long. W. | Dates of Closing | Dates of Opening | Remarks |
|---|---|---|---|---|---|
| *Nova Scotia—* | | | | | |
| Shelburne | 43 47 | 65 19 | — | — | Seldom interrupted |
| Yarmouth | 43 55 | 65 45 | — | — | Not hindered. |
| Halifax Hbr. | 44 35 | 63 33 | — | — | Frozen three times in ninety years. |
| St. John Hbr. | 45 16 | 66 4 | — | — | Not hindered. |
| Gut of Canso | 45 30 | 61 8 | Jan. 1 | April 30 | |
| Pictou Hbr. | 45 40 | 62 38 | Jan. 1 | April 10 | |
| Amherst Hbr. | 45 49 | 64 13 | Dec. 15 | April 10 | |
| Port Hood | 46 2 | 61 31 | Jan. 30 | May 1 | |
| Sydney | 46 7 | 60 18 | Jan. 10 | April 1 | |
| *New Brunswick—* | | | | | |
| Shediac | 46 12 | 64 27 | Dec 1 | April 1 | |
| Chatham | 47 1 | 65 26 | Dec. 8 | April 18 | |
| Miramichi Bay | 47 4 | 65 15 | Dec. 12 | April 13 | |
| Campbellton | 48 0 | 66 34 | Dec. 1 | May 1 | |
| *Prince Edward Is.—* | | | | | |
| Charlottetown | 46 14 | 63 8 | Dec. 21 | April 20 | |
| Summerside | 46 23 | 63 47 | Dec. 20 | April 10 | |
| *Quebec—* | | | | | |
| Father Point | 48 32 | 68 28 | Jan. 15 | March 15 | |
| Gaspe Hbr. | 48 52 | 64 30 | Dec. 15 | May 10 | |
| Seven Is. | 50 13 | 66 24 | Nov. 1 | April 15 | |
| *St. Lawrence Gulf—* | | | | | |
| St. Pierre Roadstead | 46 45 | 56 12 | — | — | Seldom interrupted. |
| Cabot Strait | 47 30 | 60 0 | Jan. 15 | April 30 | Ice "Bridge" about April 15–May 15. |
| *Newfoundland—* | | | | | |
| Port au Basques | 47 33 | 59 10 | — | — | Harbour sometimes blocked by drift ice Feb.–March. |
| La Poile Hbr. | 47 45 | 58 18 | — | — | 6 springs in 50. |
| Burgeo Port | 47 35 | 57 40 | — | — | Seldom interrupted. |
| Grand Bank Hbr. | 47 4 | 55 46 | — | — | Twice in 30 years. |
| Burin Hbr. | 47 2 | 55 14 | — | — | Seldom interrupted. |
| Trepassey Hbr. | 46 40 | 53 21 | — | — | Seldom interrupted. |
| Hearts Content Hbr. | 47 52 | 53 22 | Feb. 10 | March 31 | |
| Harbour Grace | 47 39 | 53 16 | — | — | Not hindered. |
| Cape Race | 46 38 | 53 3 | Feb. 1 | May 1 | |
| Conception Bay | 47 50 | 52 50 | Feb. 10 | April 5 | |
| St. John's Hbr. | 47 33 | 52 40 | — | — | Rarely closed for a week in an average season. |

| *Place* | *Lat. N.* | *Long. W.* | *Dates of* Closing | *Dates of* Opening | *Remarks* |
|---|---|---|---|---|---|
| *Newf'dland—ctd.—* | | | | | |
| Trinity Hbr. | 46 40 | 53 21 | — | — | Seldom interrupted. |
| Catalina Hbr. | 48 31 | 53 4 | Jan. 1 | April 15 | |
| Bonavista Bay | 48 55 | 53 10 | — | — | Generally passable. |
| Cape Freels | 49 16 | 53 27 | Jan. 15 | May 10 | |
| Gander Bay | 49 20 | 54 25 | Jan. 1 | May 1 | |
| Fortune Hbr. | 49 32 | 55 15 | Dec. 15 | May 7 | |
| St. Anthony Hbr. | 51 21 | 55 30 | Nov. 30 | May 15 | |
| Belle Isle Str. | 51 35 | 56 15 | Dec. 20 | April 1 | First steamers between June 7 and July 25, last Nov. 11–26. |
| Bay of Islands | 48 57 | 57 55 | Jan. 5 | April 30 | |
| St. George Bay | 48 50 | 58 0 | Jan. 15 | April 18 | |
| *Labrador—* | | | | | |
| Alexis R. | 52 30 | 56 0 | Dec. 25 | May 10 | |
| Lake Melville | 53 40 | 59 40 | Dec. 25 | April 15 | Heavy pack ice off approaches prevents navigation until well into June. |
| Cartwright Hbr. | 53 42 | 56 58 | Nov. 25 | May 15 | |
| Hamilton Inlet | 54 0 | 59 0 | Nov. 30 | June 15 | Mail boat operates July 1–Oct 15. |
| | | *Long. E.* | *Mean dates of* Freeze | *Mean dates of* Thaw | |
| *Arctic Coast Finland—* | | | | | |
| Kemi | 65 41 | 24 42 | Nov. 6 | May 25 | Navigation closed. Nov. 25–May 22. |
| *Russia—* | | | | | |
| Murmansk | 69 0 | 35 0 | Very irregular | | Generally ice-free. |
| Archangel | 64 33 | 39 40 | Oct. 23–Nov. 25 | May 6–30 | |
| Mezen | 65 50 | 44 23 | Oct 20–Nov. 12 | May 5–22 | |
| *Baltic Sweden—* | | | | | |
| Hernosand | 62 37 | 17 58 | Jan. 25 | April 13 | Feb. 7–April 16. |
| Umea | 63 45 | 20 20 | Nov. 12 | May 9 | Dec. 23–May 1. |
| Lulea | 65 35 | 22 10 | Dec. 25 | May 14 | |
| *Finland—* | | | | | |
| Tornio | 65 48 | 24 15 | Nov. 30 | May 24 | |
| Oulu (Uleaborg) | 65 3 | 25 35 | Dec. 10 | May 15 | |
| Vaasa | 63 38 | 21 42 | Jan. 15 | April 12 | |
| Abo (Turku) | 60 26 | 22 18 | Dec. 5 | April 17 | Navigation not interrupted. |

| *Place* | *Lat. N.* | *Long. E.* | *Mean dates of* | | *Remarks* |
|---|---|---|---|---|---|
| | | | *Freeze* | *Thaw* | |
| *Finland—contd.—* | | | | | |
| Helsinki (Helsingfors) | 60 9 | 24 57 | Dec. 11 | April 22 | Feb. 16–April 5. |
| Hango | 59 49 | 23 0 | Jan. 7 | April 7 | Navigation not interrupted. |
| Viborg (Viipuri) | 60 55 | 28 30 | Nov. 26 | April 28 | Jan. 1–April 20. |
| *Russia—* | | | | | |
| Kronstadt | 59 59 | 24 49 | Dec. 5 | April 29 | Jan. 31–April 22. |
| *Estonia* | | | | | |
| Revel (Tallinn) | 59 24 | 24 25 | Feb. 2 | April 3 | Not interrupted. |
| *Latvia—* | | | | | |
| Riga Hbr. | 56 57 | 23 30 | Dec. 26 | April 6 | March 8–April 2. |
| Windau Hbr. | 57 24 | 21 32 | Jan. 12 | Feb. 27 | Not interrupted. |
| Libau Hbr. | 56 30 | 21 0 | Jan. 8 | March 1 | Not interrupted. |
| *Black Sea* | | | | | |
| *Roumania—* | | | | | |
| Braila | 45 16 | 27 58 | Jan. 3 | March 1 | Jan. 8–Feb. 27. |
| Galatz | 45 28 | 28 4 | | | |
| Sulina | 45 10 | 29 40 | Jan. 7 | Feb. 17 | Kept open by breaker except in severe winters. |
| *Russia—* | | | | | |
| Odessa | 46 30 | 30 40 | Jan. 10 | March 15 | Ditto |
| Nikolayev (Bug) | 46 58 | 32 0 | Dec. 10 | April 1 | Dec. 25–March 20. Kept open by ice-breaker in mild winters. |
| Kherson (Dnieper) | 46 39 | 32 38 | Dec. 14 | March 25 | Dec. 24–March 18. Kept open by ice-breaker in mild winters. |
| Kerch | 45 21 | 36 28 | Dec. 28 | March 15 | Kept open except in severe winters. |
| Rostov-on-Don | 47 15 | 39 40 | Dec. 6 | March 27 | Dec. 14–March 27. |

# CHAPTER II

## THE SITING AND DESIGN OF HOUSES AND FACTORIES IN RELATION TO CLIMATE

Any building must be designed to fit its surroundings, and of these climate is the most important. If the house or factory is built to withstand rigours which rarely or never occur, it will be too expensive to build. If, on the other hand, it is too flimsy it will be expensive to heat and maintain. The factors to be considered are:—

(1) Gain or loss of heat through walls, windows and roof.
(2) Lighting.
(3) Purity of air.
(4) Local situation in regard to (*a*) frost and fog; (*b*) rain; (*c*) snow.
(5) Wind (wind pressure on buildings, dissipation of smoke).
(6) Rain and wind together (leaking of walls).

A. Geddes (1946) recommends that the distribution of the climatic factors should be sketched in on contour maps on a scale of 1 inch or 6 inches to the mile, but he points out that not only the existing climate is to be considered, but what it will be after building is completed.

The constructional details are, of course, a matter for the architect; the following pages give a summary of the necessary climatic basis, as far as it is available.

### GAIN OR LOSS OF HEAT THROUGH WALLS, WINDOWS AND ROOF

The heat balance of a building is very complicated. A building is heated by the absorption of solar radiation and, in hot weather, by conduction from the air. It is cooled by radiation from the walls and roof, by evaporation from wet surfaces, and, in cold and especially windy weather, by conduction to the air. In a hot climate the problem is to resist the absorption of external heat, especially of direct radiation from the sun; in a cold climate the problem is to conserve the heat, produced internally, against conduction to the external air.

*Solar Radiation.*—The amount of heat received from the sun depends on the elevation of the sun above the horizon, the amount of cloud, and the purity of the air. At the outer limit of the earth's atmosphere the sun's rays have a heating power of nearly two calories per sq. cm. per minute, equivalent to one B.T.U. on 20 square inches. Part of this heat is absorbed by water vapour and other gases in the atmosphere, part is reflected from the upper surfaces of clouds, and part is scattered by the molecules of air and dust particles in the atmosphere.

The visible part of the sun's rays accounts for the greater part of the heating effect, but there are also rays invisible to the human eye. At one end of the scale these include the *ultra-violet* radiation, which has powerful chemical effects. These rays cause chemical changes in the skin which are visible as sunburn, but they also have health-giving properties. It is the shutting-off of the ultra-violet radiation by smoke and fog which is mainly responsible for the pallid appearance of city dwellers, and for the tendency to rickets among city children. The direct heating power of these rays is small. At the other end of the scale the infra-red (sometimes called ultra-red) rays have considerable heating power; these are not much affected by smoke, but are powerfully absorbed by water vapour.

The upper surfaces of thick clouds reflect about three-quarters of the sun's radiation back to space. This means a great loss of heating power, which is accentuated because in cloudy regions the amount of water vapour in the air is also relatively great. Hence the highest day temperatures, exceeding 130° F. in the shade, are found in dry climates in tropical and sub-tropical regions where there is little or no cloud. In moist, cloudy, equatorial regions the air temperature rarely rises above 100° F.

On the other hand, both water vapour and cloud have a great effect in *conserving* heat at night. The earth gives back at night and in winter the heat it has absorbed from the sun by day and in summer. This heat is given up as infra-red radiation, which is rapidly absorbed by water, whether as vapour or cloud droplets. In a moist climate the heat cannot readily escape and the nights are warm and muggy. In a dry climate the heat gained during the day is rapidly lost after sunset, and the nights are cold. For this reason buildings in hot

dry climates should have thick walls, shaded by wide verandas, and thick roofs, preferably double, to equalise the temperature of the interior. Windows should as far as possible be sheltered from direct sunshine by verandas and, outside the tropics, by being placed mainly on the north side (in the northern hemisphere). Apart from this, ample opening space of windows facilitates ventilation during the cooler times of day. The type of building favoured by local residents should be studied, as this has been developed as a result of long experience. In hilly countries with hot summers it may be possible to select a house-site to take advantage of the cool breeze which blows down the hillsides at night, and to make the best use of it by building summer sleeping porches on the upslope side of the house.

The neighbourhood of small lakes is an unfavourable situation in places with hot summers. A small or shallow body of water reaches a high temperature, and active evaporation makes the lowest layers of air very humid, especially in calm, sunny weather. On the other hand, lakes large and deep enough to absorb the sun's heat without warming up appreciably have a cooling and moderating effect on the air.

The effect of *position* in a building was shown by A. J. ter Linden (1938), who obtained autographic records of the indoor temperature and relative humidity of a number of rooms in Delft, Holland, during the rather cool summer of 1937, with the outdoor temperature for comparison. In a room on the ground floor of a large building with windows facing east and north, the temperature was very steady at about the average of the outdoor temperature; relative humidity was also steady, between 60 and 70 per cent. At the other extreme, in a room with large windows north and south, immediately under a flat roof, a marked "greenhouse" effect was found; the room temperature ranged from 66° to 76° F., while the outdoor temperature was between 46° and 64° F. The indoor maxima and minima lagged two or three hours behind those of the exterior. Relative humidity remained around 50 per cent. A room immediately below a flat roof, but with windows only to the east, showed an intermediate effect. The type of roof is important; ter Linden points out that in hot weather gabled roofs with a good airspace below give much more comfortable conditions in the rooms on the top floor than do flat roofs. If

the latter are insufficiently insulated the top story is likely to be unhealthily hot and dry.

No observations seem to exist of temperatures inside buildings with walls of different thicknesses, but an idea of the effect may be obtained from soil temperatures at different depths. On Salisbury Plain N. K. Johnson and E. L. Davies (1927) found that the logarithm of the daily range of temperature is proportional to the depth below one inch. At 5 inches the range was reduced to one-tenth, and at 10 inches to one-hundredth, of that at one inch. The character of the soil made little difference. At Cairo, on a hot day on which the surface of sandy soil had a daily range of 57° F., the range was only 6·5° F. at a depth of 8 inches. From this it is seen that the high temperatures of earthy or stony materials exposed to the sun are very superficial.

The part played by the colour of the walls in modifying the effect of the sun's heat may be judged from some experiments at Poona in India. Black soil in May reached a temperature of 64·6° C. (148° F.), brown soil of 58° C. (136° F.), and soil covered with white powder only 48° C. (118° F.). Throughout the tropics the surfaces of dark-coloured bricks, tarred roads, etc., exposed to the sun reach temperatures of 130–140° F., and may exceed 160° in hot, dry regions. It must be remarked, however, that while white walls and roads are most efficient in reflecting the sun's heat, they also reflect the glare and are very exhausting to the eyes. For that reason the tendency is to replace white by some light colour. Most roofing materials in use absorb about 90 per cent. of the sun's radiation; galvanised iron absorbs roughly two-thirds. The effect of *colour* is discussed more fully in Chapter IX.

The effect of the elevation of the sun on the intensity of solar radiation is very great. In passing through a unit thickness of air the rays lose a certain proportion of their power. The unit adopted is the thickness of air traversed by the sun when it is vertically overhead; this is termed "air mass 1." In clear, dry weather with a vertical sun about 85 per cent. of the solar energy reaches low ground; in damp, humid weather such as is generally found near the Equator the ratio is about 75 per cent. In large towns with a smoky atmosphere the loss of energy is much greater.

The thickness of air traversed when the sun is at different

altitudes, and the maximum solar radiation reaching the ground in dry and humid air (transmission coefficients 85 and 75 per cent.) are shown in Table 7. The figures in lines (3) and (4) refer to a surface at right angles to the sun's rays; lines (5) and (6) show the radiation reaching a *horizontal* surface. The figures are in calories /cm.$^2$/min., assuming that the value at the limit of the atmosphere is 1·93. The lowest two lines show the direct solar radiation falling on a vertical wall facing south (in the northern hemisphere).

TABLE 7.—Height of sun, air mass and heat received.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| (1) Height of sun . | 90° | 70° | 50° | 30° | 20° | 15° | 10° | 5° |
| (2) Air mass . . | 1·0 | 1·064 | 1·305 | 1·995 | 2·9 | 3·81 | 5·6 | 10·4 |
| Radiation at sea level. | | | | | | | | |
| Normal to rays. | | | | | | | | |
| (3) Dry air . . | 1·64 | 1·62 | 1·56 | 1·4 | 1·21 | 1·04 | 0·78 | 0·36 |
| (4) Humid air . | 1·45 | 1·41 | 1·33 | 1·09 | 0·84 | 0·65 | 0·39 | 0·1 |
| Horizontal surface. | | | | | | | | |
| (5) Dry air . . | 1·64 | 1·52 | 1·2 | 0·7 | 0·41 | 0·27 | 0·13 | 0·03 |
| (6) Humid air . | 1·45 | 1·33 | 1·02 | 0·54 | 0·29 | 0·17 | 0·07 | 0·01 |
| Vertical S. wall | | | | | | | | |
| (7) Dry air . . | 0·0 | 0·56 | 1·0 | 1·21 | 1·13 | 1·01 | 0·77 | 0·35 |
| (8) Humid air . . | 0·0 | 0·48 | 0·85 | 0·94 | 0·79 | 0·62 | 0·38 | 0·1 |

At noon in March and September the elevation of the sun is equal to 90° minus the latitude. At midsummer outside the tropics it is 113° minus the latitude, and in midwinter 67° minus the latitude. North of 67° the sun does not appear at all in midwinter. The altitude of the sun at noon on any day is equal to 90° minus the positive difference between the latitude and the sun's declination.

The effect of the greater absorption by the air in higher latitudes, due to the greater thickness of air traversed, is magnified by the fact that, owing to the greater inclination of the sun's rays on level surfaces the same amount of energy is spread out over a greater area. The decrease in the amount of heat from the sun received on the ground and on flat roofs in higher latitudes is partly compensated by the gain on vertical walls facing south, but this gain is small. Buildings are warmed not only by direct sunshine, but also by heat reflected or radiated from the ground, and this depends on the angle of the sun's rays.

The sun's declination at noon on the middle day of each

month, and the noon altitude of the sun in 50° N., are approximately as follows:—

TABLE 8.—Sun's declination and altitude.

Solar Declination—

| Jan. 15 | Feb. 14 | March 15 | April 15 | May 15 | June 15 | July 15 | Aug. 15 | Sept. 15 | Oct. 15 | Nov. 15 | Dec. 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| −21° 19′ | −13° 23′ | −2° 34′ | +9° 22′ | +18° 36′ | +23° 16′ | +21° 42′ | +14° 24′ | +3° 27′ | −8° 6′ | −18° 12′ | −23° 13′ |

Noon Altitude in 50° N.

| Jan. 15 | Feb. 14 | March 15 | April 15 | May 15 | June 15 | July 15 | Aug. 15 | Sept. 15 | Oct. 15 | Nov. 15 | Dec. 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 19° | 27° | 38° | 49° | 59° | 63° | 62° | 54° | 43° | 32° | 22° | 17° |

The effect of solar heating is modified by the elevation of the ground and its slope. Over high ground the amount of air is less than over low ground, and its power of absorption is correspondingly less. That accounts for the strong sunshine of mountain resorts, which goes a long way towards counterbalancing the low air temperature. At a height of 3,000 feet the air mass is reduced by about one-tenth, so that at 3,000 feet in latitude 50° the strength of the sun's rays is equivalent to that at sea-level in latitude 45°. In humid or smoky places the effect is greater than this because much of the moisture and most of the smoke is confined to the lowest tenth of the air.

The effect of a southerly slope (in the northern hemisphere) is in some ways similar to transfer to a lower latitude. The radiation received on flat roofs and vertical walls is of course unchanged, but the radiation received on the ground is increased. Ground sloping south becomes warmer than level ground, and part of this extra heat is given up to the buildings. Also the area shaded by the buildings is smaller. On ground sloping north the effect is reversed. In middle northern latitudes the effect of a south slope of one in ten on clear days is to increase the heating effect on the ground by about 15 per cent.; a slope of one in ten to the north decreases the heating effect by the same amount. On cloudy days there is little difference between different slopes. On a southerly slope there is some loss of radiation in summer before 6 a.m. and after 6 p.m., but this is relatively unimportant. The effect of an

easterly slope is to increase the warming effect in the morning and decrease that in the afternoon; the "radiation day" both begins and ends earlier. Similarly, the effect of a westerly slope is to make the radiation day begin and end later. A northerly slope is altogether unfavourable, except in the early morning and late evening.

The total radiation received on vertical walls depends on the season and the direction in which the wall faces. For the year as a whole it is greatest on walls facing south and least on walls facing north, but in summer, south of about 55° N., the sun is so high at noon that the direct heating effect on vertical walls is small, and for this reason most heat is received on walls facing south-east and south-west.

J. M. Stagg (1950) gives data for the components of direct solar radiation which fall on surfaces facing in different directions at Kew Observatory, Richmond, representative of the outskirts of London. The following table, based on data for all days in the period 1933 to 1946, has been constructed from these data (unit, gm.cal./cm.²/day).

TABLE 9.—Daily averages of direct radiation on differently oriented surfaces.

| Month | Jan. | Feb. | Mar. | Apr. | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. | Mean |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Normal to sun | 38 | 72 | 130 | 192 | 258 | 294 | 245 | 234 | 181 | 108 | 49 | 36 | 153 |
| Vertical walls facing | | | | | | | | | | | | | |
| south | 33 | 55 | 78 | 80 | 74 | 66 | 56 | 73 | 93 | 75 | 41 | 31 | 63 |
| north | — | — | — | 2 | 11 | 20 | 13 | 4 | — | — | — | — | 4 |
| east or west | 7 | 17 | 36 | 58 | 79 | 91 | 70 | 64 | 52 | 27 | 10 | 7 | 43 |
| Horizontal surface | 9 | 23 | 55 | 102 | 153 | 182 | 139 | 121 | 86 | 40 | 13 | 7 | 77 |

One gm.cal. equals 4·18 joules, or 0·00397 B.T.U. Thus a radiation of 1 gm.cal./cm.² equals 3·7 B.T.U. per square foot.

Radiation on a wall facing in any other direction, or on a slope, is readily calculated by combining the figures from the directions on either side. For example, a wall facing SSE. makes an angle of 22½° with a wall facing south and an angle of 67½° with a wall facing east. To find the radiation on such a wall, we multiply the radiation on a south wall by the cosine of 22½° or 0·924, and that on an east wall by the cosine of 67½° or 0·383. The resulting figures are squared and added and the square root taken. Thus, in June the radiation on a wall

facing SSE. is $\sqrt{[(66\times 0{\cdot}924)^2+(91\times 0{\cdot}383)^2]}=70$ gm.cal./cm.$^2$/day. On the clearest days the radiation is much stronger, amounting in June to 1,035 gm.cal./cm.$^2$ normal to the sun, 642 on a horizontal surface and 319 on a wall facing east or west.

In addition to direct solar radiation the earth receives radiation from the sky. This takes two forms: (1) diffuse short-wave radiation, which is simply solar radiation scattered by water drops, dust particles and gas molecules during its passage through the air; (2) long-wave radiation from the clouds and the air itself. Both these types of radiation come from all directions, though the diffuse radiation is greatest from the neighbourhood of the sun and least from near the horizon. The diffuse short-wave radiation on a horizontal surface at Kew ranges from about twice the direct solar radiation on a horizontal surface in winter to about equal to the latter in summer. It is greatest on thinly clouded days and least on heavily clouded days. Since a vertical wall receives radiation from only half the sky, the diffuse radiation on a wall facing in any direction may be taken as about half that falling on a horizontal surface, *i.e.* about equal to the bottom line of Table 9 from October to March, half the bottom line from April to August, and four-fifths of it in September.

The long-wave radiation from air and clouds is small on clear days but becomes more important on cloudy days, when it amounts to about 12 gm.cal./cm.$^2$/day on a horizontal surface. Allowing for radiation from the ground, the total long-wave radiation on one side of a vertical wall may be taken as rather less than this in winter and rather more in summer.

Measurements of direct and diffuse solar radiation are not available for many places, but an approximate calculation of the direct solar radiation under clear skies in any latitude can be made without much difficulty. The "solar constant" is 1·93 gm.cal./cm.$^2$/min.; this is the radiation at the limit of the earth's atmosphere. The transmission coefficient, or the proportion of radiation reaching sea-level under a vertical sun, may be taken as about 0·85 in dry regions, about 0·8 in average climates such as prevail in most of Europe and North America, and 0·75 in moist equatorial climates and in the rainy season in monsoon climates. If we write $t$ for this transmission coefficient and $a$ for the air-mass, or length of the path of the sun's rays through the atmosphere, while $I$ (in gm.cal./cm.$^2$/min.)

is the intensity of the solar radiation on a plane normal to the sun's rays at the surface of the earth, then

$$\log I = 0{\cdot}2856 + a \log t.$$

The air-mass $a$ depends on the zenith distance $z$ of the sun, and is approximately equal to sec $z$. $z$ can be found from the following expression:—

$$\cos z = \cos P \cos \phi \cos \delta + \sin \phi \sin \delta.$$

Here $\phi$ is the latitude, $\delta$ is the sun's declination, and P is the "hour-angle," *i.e.* the number of hours before or after local noon, converted to angular measure at the rate of 15° per hour.

Having found $I$ for, say, each hour, the values can be split up into their components on a horizontal plane and on walls facing south, east and west, multiplied by sixty to convert to radiation per hour, and by any other factors to bring to the units required, and added together to give the total radiation during the day. This method was tried out for latitude 52° N. for 15th March, using a transmission coefficient of 0·8, and gave totals about equal to those found by Stagg on bright days in March.

The elevation and azimuth of the sun at any time can be found graphically by the use of a simple diagram. A convenient one was published by the U.S. Hydrographic Office on the back of the *Pilot Chart of the Central American Waters* for May 1941; a simplified and reduced version of this is reproduced in Fig. 9 to illustrate the principle, but for accurate work the original should be consulted.

To find the height of the sun at any time, first find the latitude of the place, and the declination of the sun on the day in question. Add these and find the corresponding point $C_1$ on the upper scale of the triangle. Subtract them and find the corresponding point $C_2$ on the lower scale. Draw straight lines from $C_1$ to $A_1$ and from $C_2$ to $A_2$ and mark the point of intersection X of these two lines (the sloping lines on the triangle all intersect at $A_1$ or $A_2$, so that the point of intersection can be found by interpolating between these lines). Next find the hour-angle of the sun, *i.e.* the difference in hours between the time required and local noon, multiplied by 15. For accurate results a correction must be made for the equation of time, or the difference between noon by local time and apparent noon

by the sun. Sun time (as shown, for example, by a sundial) is behind clock time in January, February and March, the difference reaching nearly 15 minutes in February, and again by a small amount in July and August. Sun time is "fast" by the clock by a small amount in May and again in September to December, the difference exceeding 15 minutes from about

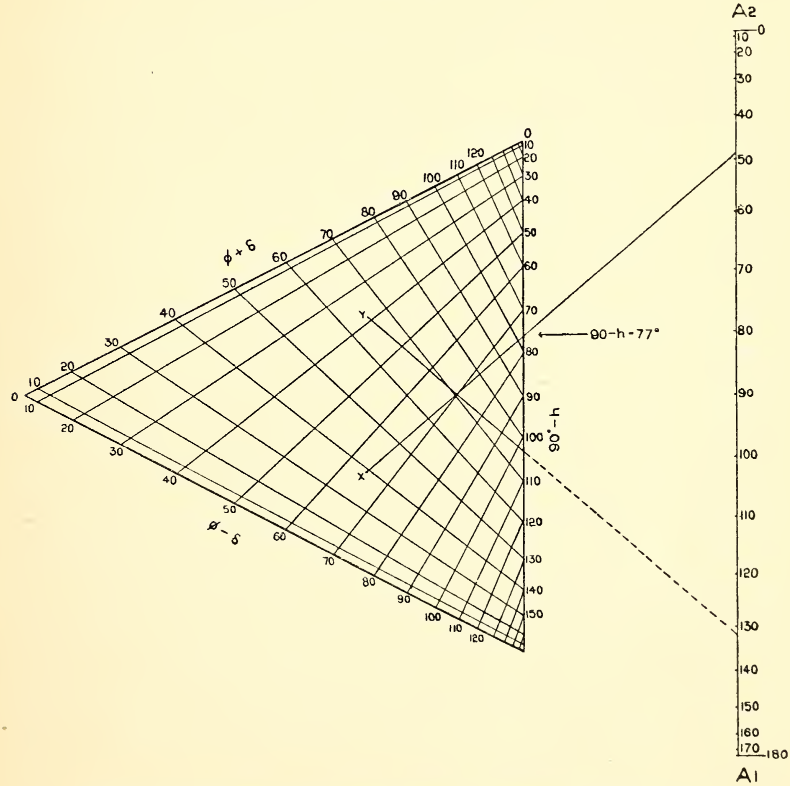


Fig. 9.—Diagram for height and aximuth of the sun.

20th October to 17th November. The corrections to clock time are to the nearest half-minute on the 15th of each month (data for 1946):—

| Jan. | Feb. | Mar. | April | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| −9½ | −14½ | −9 | 0 | +4 | 0 | −6 | −4½ | +4½ | +14 | +15½ | +5 |

Having found the hour-angle of the sun, mark this point on the line $A_1A_2$ and draw a line from it to the point X. The

intersection of this line with the scale $90-h$ gives the distance of the sun below the zenith, from which the height $h$ of the sun can be obtained directly.

To find the azimuth of the sun, having first found $h$, mark the point Y in the triangle representing $\phi+h$ and $\phi-h$, and join this to the point on the $h$ scale given by $90-\delta$. The intersection of the extension of this line with the $90-h$ scale gives the azimuth in degrees from north through east (morning) or west (afternoon).

*Example.*—Consider a point in lat. 52° N. at 9 a.m. local time on 14th February. The sun's declination $\delta$ is $-13°$, so that $\phi+\delta$ is 39° and $\phi-\delta$ is 65°. The sun time is nine hours less nearly 15 minutes (equation of time), so that the hour-angle is $15\times3\frac{1}{4}=49°$. Joining these two points we find that $90-h=77°$, so that $h=13°$. $\phi+h=65°$ and $\phi-h=39°$ in the triangle and $90-\delta=103°$ on the $h$ scale. Joining these points and extending to the A scale we find that the azimuth is 132°, *i.e.* the sun is $132-90=42°$ south of east.

Alternate exposure to strong sunshine and low night temperatures causes expansion and contraction of walls and roofs. In such situations it is best to avoid as far as possible the mixture of building materials with different coefficients of expansion. In Europe the range of surface temperature may be as much as 100° F., and in dry sub-tropical countries such as Iraq and Iran and in the south-western United States even more. The coefficient of linear expansion $\alpha$ is given by the relation $l_t=l_o\ (l+\alpha t)$, where $l_o$ is the length of a bar of the material at a temperature of 0° C. and $l_t$ is the length at a higher temperature $t$° C. Approximate values of the coefficient $\alpha$ for temperatures between 0° and 20° C. (32° and 68° F.) expressed in units of $10^{-6}$ (·000001) are:—

| | | | |
|---|---|---|---|
| Iron and steel | 10 to 12 | Cement and concrete | 10 to 14 |
| Brick | 9 to 10 | Sandstone | 7 to 12 |
| Glass | About 9 | | |

A coefficient of 10 in these units means that a bar of the material increases by 1/10,000 of its length with a rise of temperature by 10° C. (18° F.). An iron girder 100 feet long at 32° F. would be about half an inch longer at 100° F. Wooden beams do not increase appreciably in length on heating, but their cross-section increases slightly. The coefficients of expansion of wood (in the unit used above) are 3 to 5 along the grain and 34 to 60

across the grain. But the effect of heat on wood is masked by the much greater effect of humidity.

*Duration of bright sunshine.*—In view of the importance of sunshine not only for heating buildings, but for many other aspects of life, Table 10 has been constructed to give the average duration of bright sunshine in each month in hours per day. "Bright" sunshine is defined as sunshine sufficiently powerful to operate a Campbell-Stokes sunshine recorder, in which the sun's rays are focused by a glass sphere on to a strip of card, where they leave a charred trace as the sun moves across the sky. The sun can burn the card even when shining through thin cloud, but it must be bright enough to cast a clear shadow. On the other hand, the sun does not burn the card when it is near the horizon; the limiting range is generally 3–5°, but in the smoky atmosphere of large towns sunshine may not be recorded unless the sun is 10° or more above the horizon.

Most of the averages in Table 10 were obtained with Campbell-Stokes recorders, some by other instruments. They have been extracted from the official publications of the various Meteorological Services. Where instrumental records of sunshine are not available the duration can be estimated from observations of cloud amount by a method designed by C. E. P. Brooks (1929).

*Loss of heat in cold weather.*—In cold climates the main problem is to prevent excessive loss of heat in winter. The extent of this loss is well brought out by the comparison of observations of temperature on the roof of Victory House, Kingsway, London, and in the nearby open space of Kensington Palace (W. A. L. Marshall, 1948). On the average of a complete year the roof was only about 1° F. warmer than the open space, but the difference was much greater in winter and at night. The night minima in January and February averaged 3° F. warmer on the roof than in the open, and in periods of severe frost the difference might be as great as 8–10° F., though part of this difference was due to the natural increase of temperature upwards on cold clear nights. Similar results were found at Debrecen, Hungary, by D. Berenyi (1948). The greater part of the loss of heat is due to conduction to the outside air.

This depends on: (1) the thickness of the walls and roof; (2) the insulating property of the materials; (3) the surface

TABLE 10.—Average duration of bright sunshine, hours per day.

| Place | Jan. | Feb. | March | April | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. | Year |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Great Britain*— | | | | | | | | | | | | | |
| Birmingham | 1·4 | 1·9 | 2·9 | 4·4 | 5·7 | 5·9 | 5·5 | 5·2 | 4·1 | 2·8 | 1·7 | 1·1 | 3·6 |
| Cardiff | 1·7 | 2·5 | 3·7 | 5·7 | 6·7 | 7·5 | 6·7 | 5·9 | 4·9 | 3·5 | 2·3 | 1·6 | 4·4 |
| Edinburgh | 1·5 | 2·5 | 3·5 | 4·7 | 5·3 | 6·3 | 5·3 | 4·7 | 4·3 | 3·2 | 2·1 | 1·4 | 3·7 |
| London (Kew) | 1·4 | 2·1 | 3·3 | 5·0 | 6·5 | 6·7 | 6·3 | 5·9 | 4·8 | 3·0 | 1·8 | 1·2 | 4·0 |
| Manchester | 0·4 | 1·0 | 2·4 | 3·8 | 4·6 | 5·2 | 4·4 | 3·7 | 3·4 | 2·0 | 0·6 | 0·2 | 2·7 |
| *Austria*— | | | | | | | | | | | | | |
| Innsbruck | 2·2 | 3·7 | 4·8 | 5·1 | 6·2 | 6·2 | 6·4 | 6·5 | 5·6 | 4·5 | 2·8 | 1·7 | 4·6 |
| Vienna | 1·9 | 2·8 | 4·1 | 5·7 | 7·6 | 8·0 | 8·4 | 7·8 | 5·9 | 3·5 | 2·1 | 1·4 | 4·9 |
| *Belgium*— | | | | | | | | | | | | | |
| Brussels | 1·7 | 2·9 | 3·9 | 5·3 | 6·9 | 6·7 | 6·6 | 6·5 | 5·4 | 3·6 | 2·0 | 1·3 | 4·4 |
| *Bulgaria*— | | | | | | | | | | | | | |
| Sofia | 1·9 | 2·9 | 4·1 | 5·7 | 7·2 | 8·6 | 9·6 | 9·2 | 6·7 | 4·3 | 2·7 | 1·8 | 5·4 |
| *Czechoslovakia*— | | | | | | | | | | | | | |
| Brno | 1·8 | 1·8 | 3·1 | 5·2 | 6·4 | 5·9 | 6·9 | 7·0 | 4·5 | 2·6 | 1·9 | 1·0 | 4·0 |
| Prague | 1·7 | 3·0 | 4·6 | 5·6 | 7·7 | 7·5 | 8·4 | 7·3 | 5·6 | 3·5 | 1·7 | 1·4 | 4·8 |
| *Denmark*— | | | | | | | | | | | | | |
| Copenhagen | 0·9 | 1·6 | 3·0 | 5·2 | 7·5 | 7·9 | 7·2 | 5·6 | 4·8 | 2·7 | 1·2 | 0·4 | 4·0 |
| *Eire*— | | | | | | | | | | | | | |
| Dublin | 1·7 | 2·6 | 3·8 | 5·4 | 6·0 | 6·2 | 5·5 | 5·0 | 4·4 | 3·1 | 2·3 | 1·5 | 4·0 |
| *Estonia*— | | | | | | | | | | | | | |
| Tartu | 1·1 | 1·9 | 4·0 | 6·2 | 8·2 | 9·1 | 9·1 | 6·5 | 5·0 | 2·8 | 0·8 | 0·6 | 4·6 |
| *Finland*— | | | | | | | | | | | | | |
| Helsinki | 0·8 | 1·8 | 3·5 | 5·0 | 8·1 | 8·3 | 9·6 | 6·6 | 4·1 | 2·3 | 0·8 | 0·4 | 4·3 |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *France*— | | | | | | | | | | | | | |
| Lyons | 1·8 | 3·1 | 4·6 | 5·4 | 6·4 | 7·2 | 8·1 | 8·0 | 6·4 | 3·9 | 2·1 | 1·4 | 4·9 |
| Nice | 4·7 | 5·6 | 6·3 | 7·1 | 8·6 | 9·6 | 10·7 | 10·4 | 8·0 | 6·3 | 4·6 | 4·5 | 7·2 |
| Paris | 2·0 | 4·0 | 4·2 | 5·6 | 7·0 | 7·4 | 7·7 | 7·4 | 5·6 | 3·8 | 2·2 | 1·5 | 4·9 |
| Strasbourg | 1·8 | 2·5 | 3·4 | 5·1 | 6·3 | 6·8 | 7·0 | 6·6 | 4·4 | 3·0 | 1·6 | 1·1 | 4·1 |
| *Germany*— | | | | | | | | | | | | | |
| Berlin | 1·7 | 2·4 | 3·5 | 5·4 | 7·3 | 7·8 | 7·0 | 6·6 | 5·0 | 3·3 | 1·9 | 1·5 | 4·4 |
| Hamburg | 1·1 | 1·9 | 3·0 | 5·4 | 6·5 | 6·2 | 5·5 | 5·8 | 4·8 | 2·7 | 1·3 | 0·6 | 3·7 |
| Leipzig | 1·9 | 2·9 | 4·0 | 5·2 | 7·3 | 7·2 | 7·8 | 6·9 | 5·1 | 3·5 | 2·2 | 1·5 | 4·6 |
| Munich | 1·8 | 3·4 | 4·8 | 5·3 | 7·6 | 7·8 | 8·7 | 7·6 | 6·0 | 4·1 | 1·9 | 1·2 | 5·0 |
| *Greece*— | | | | | | | | | | | | | |
| Athens | 4·6 | 5·4 | 6·2 | 7·8 | 8·5 | 10·6 | 11·9 | 11·1 | 9·2 | 6·9 | 4·8 | 4·1 | 7·6 |
| *Holland*— | | | | | | | | | | | | | |
| Utrecht | 1·8 | 2·6 | 3·8 | 5·4 | 7·0 | 6·8 | 6·6 | 6·0 | 5·1 | 3·3 | 2·1 | 1·3 | 4·3 |
| *Hungary*— | | | | | | | | | | | | | |
| Budapest | 1·9 | 2·7 | 4·3 | 6·0 | 8·5 | 9·1 | 9·5 | 8·8 | 6·3 | 4·5 | 2·4 | 1·3 | 5·4 |
| *Italy*— | | | | | | | | | | | | | |
| Genoa | 3·6 | 4·8 | 5·5 | 6·1 | 7·2 | 7·4 | 9·0 | 9·1 | 6·6 | 5·4 | 3·5 | 2·9 | 5·9 |
| Rome | 3·7 | 4·8 | 5·0 | 5·9 | 7·3 | 9·0 | 11·2 | 10·0 | 7·0 | 5·2 | 4·4 | 3·5 | 6·4 |
| Venice | 2·1 | 3·4 | 2·9 | 3·7 | 6·1 | 7·5 | 9·1 | 9·1 | 4·1 | 3·3 | 1·8 | 1·2 | 4·5 |
| *Latvia*— | | | | | | | | | | | | | |
| Riga | 1·1 | 1·9 | 3·3 | 6·1 | 8·9 | 8·7 | 8·5 | 6·7 | 5·1 | 2·8 | 1·2 | 0·4 | 4·6 |
| *Lithuania*— | | | | | | | | | | | | | |
| Kaunas | 1·3 | 2·0 | 3·9 | 5·9 | 8·3 | 9·3 | 8·8 | 7·1 | 5·5 | 3·0 | 1·3 | 0·8 | 4·8 |
| *Poland*— | | | | | | | | | | | | | |
| Danzig | 1·4 | 2·3 | 4·5 | 5·9 | 8·1 | 9·5 | 8·7 | 7·5 | 5·9 | 3·7 | 2·1 | 1·2 | 5·1 |
| Warsaw | 1·5 | 2·2 | 4·1 | 5·0 | 6·8 | 6·9 | 7·2 | 6·7 | 5·1 | 3·6 | 1·9 | 0·9 | 4·3 |
| *Portugal*— | | | | | | | | | | | | | |
| Lisbon | 4·8 | 5·4 | 6·4 | 8·0 | 9·0 | 10·1 | 11·1 | 11·1 | 8·6 | 6·4 | 4·8 | 4·3 | 7·5 |

TABLE 10.—Average duration of bright sunshine, hours per day—*continued.*

| Place | Jan. | Feb. | March | April | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. | Year |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Roumania*— | | | | | | | | | | | | | |
| Bucharest | 2·7 | 3·7 | 4·9 | 6·9 | 8·2 | 9·3 | 10·7 | 10·5 | 8·2 | 5·5 | 3·3 | 2·1 | 6·3 |
| *Spain*— | | | | | | | | | | | | | |
| Barcelona | 4·8 | 6·2 | 6·2 | 7·7 | 8·7 | 9·5 | 10·5 | 9·4 | 7·6 | 6·6 | 5·2 | 4·5 | 7·2 |
| Madrid | 5·1 | 6·4 | 7·0 | 8·6 | 9·4 | 11·1 | 12·4 | 11·4 | 8·6 | 6·6 | 4·7 | 4·3 | 8·0 |
| *Sweden*— | | | | | | | | | | | | | |
| Stockholm | 1·3 | 2·3 | 4·1 | 6·4 | 8·7 | 9·4 | 9·0 | 6·9 | 5·4 | 2·9 | 1·2 | 0·7 | 4·9 |
| *Switzerland*— | | | | | | | | | | | | | |
| Berne | 2·1 | 3·7 | 4·6 | 5·5 | 7·1 | 7·9 | 8·8 | 8·5 | 6·4 | 4·4 | 2·2 | 1·5 | 5·2 |
| Lugano | 4·0 | 5·3 | 6·0 | 6·2 | 6·8 | 8·4 | 9·4 | 8·9 | 7·0 | 4·7 | 3·3 | 3·9 | 6·3 |
| Zurich | 1·5 | 3·0 | 4·1 | 5·1 | 6·5 | 7·2 | 7·7 | 7·4 | 5·3 | 3·2 | 1·6 | 1·2 | 4·5 |
| *U.S.S.R.*— | | | | | | | | | | | | | |
| Leningrad | 0·4 | 1·6 | 1·4 | 2·2 | 3·1 | 3·9 | 4·0 | 2·5 | 1·5 | 0·3 | 0·1 | 0·0 | 1·8 |
| Moscow | 0·1 | 0·4 | 1·9 | 2·4 | 3·3 | 4·0 | 4·3 | 3·7 | 2·3 | 0·6 | 0·1 | 0·1 | 1·9 |
| Vladivostok | 6·1 | 6·8 | 7·1 | 6·5 | 6·9 | 6·1 | 5·1 | 6·5 | 7·4 | 6·7 | 6·2 | 6·7 | 6·5 |
| *Yugoslavia*— | | | | | | | | | | | | | |
| Belgrade | 1·8 | 3·4 | 4·7 | 6·3 | 8·4 | 9·4 | 10·5 | 9·5 | 7·2 | 4·9 | 3·9 | 1·6 | 6·0 |
| *Malta*— | 5·1 | 5·7 | 6·8 | 8·6 | 9·6 | 10·8 | 12·0 | 11·2 | 9·1 | 7·3 | 5·7 | 5·1 | 8·1 |
| *China*— | | | | | | | | | | | | | |
| Hongkong | 4·7 | 3·4 | 3·1 | 3·9 | 5·1 | 5·5 | 6·8 | 6·6 | 6·6 | 7·0 | 6·3 | 5·6 | 5·4 |
| Nanking | 4·4 | 4·3 | 5·4 | 4·9 | 6·5 | 6·2 | 7·9 | 7·6 | 6·5 | 6·5 | 5·3 | 3·8 | 5·8 |
| Shanghai | 3·9 | 3·6 | 4·3 | 4·8 | 5·7 | 4·5 | 6·9 | 7·2 | 5·3 | 5·7 | 4·9 | 4·7 | 5·1 |
| *Formosa*— | | | | | | | | | | | | | |
| Taihoku | 2·7 | 2·5 | 2·8 | 3·6 | 4·1 | 5·8 | 7·6 | 7·1 | 6·4 | 4·5 | 3·8 | 2·8 | 4·5 |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *India*— | | | | | | | | | | | | | |
| Allahabad | 8·6 | 10·1 | 9·9 | 10·6 | 10·0 | 7·3 | 5·3 | 4·7 | 7·9 | 8·9 | 9·9 | 8·4 | 8·5 |
| Bangalore | 8·5 | 9·5 | 9·5 | 9·2 | 8·7 | 5·8 | 4·1 | 4·6 | 5·6 | 6·3 | 6·0 | 7·9 | 7·1 |
| Bombay | 9·8 | 10·2 | 10·0 | 10·5 | 10·5 | 5·8 | 2·3 | 3·2 | 5·5 | 8·1 | 9·3 | 9·7 | 7·9 |
| Calcutta | 7·7 | 7·9 | 7·8 | 8·0 | 7·9 | 4·5 | 3·4 | 3·9 | 4·6 | 7·0 | 8·0 | 7·9 | 6·5 |
| Madras | 6·9 | 8·8 | 8·8 | 9·0 | 7·3 | 5·3 | 3·8 | 4·8 | 5·2 | 5·4 | 4·7 | 5·8 | 6·3 |
| *Indochina*— | | | | | | | | | | | | | |
| Phulien | 2·8 | 2·0 | 1·5 | 2·8 | 5·7 | 5·8 | 5·9 | 5·1 | 6·1 | 6·0 | 5·0 | 3·8 | 4·4 |
| *Japan*— | | | | | | | | | | | | | |
| Nagasaki | 3·7 | 4·2 | 5·7 | 6·1 | 6·8 | 4·5 | 7·3 | 8·1 | 6·1 | 6·2 | 5·2 | 3·8 | 5·6 |
| Tokio | 6·1 | 6·0 | 6·0 | 6·2 | 6·4 | 5·1 | 6·3 | 6·7 | 4·6 | 4·6 | 5·6 | 5·9 | 5·8 |
| *Korea*— | | | | | | | | | | | | | |
| Jinsen | 6·1 | 7·1 | 7·5 | 8·1 | 8·0 | 7·8 | 5·9 | 7·2 | 7·2 | 7·5 | 6·2 | 5·7 | 7·0 |
| *Malaya*— | | | | | | | | | | | | | |
| Singapore | 6·0 | 7·1 | 6·2 | 6·2 | 6·1 | 5·6 | 7·2 | 7·4 | 5·4 | 5·4 | 5·2 | 4·8 | 6·1 |
| *Manchuria*— | | | | | | | | | | | | | |
| Mukden | 6·3 | 7·3 | 7·6 | 8·1 | 8·2 | 8·6 | 7·4 | 7·5 | 7·5 | 7·0 | 5·9 | 5·8 | 7·3 |
| *Transjordan*— | | | | | | | | | | | | | |
| Amman | 6·4 | 7·1 | 8·9 | 10·3 | 11·3 | 13·1 | 13·1 | 12·5 | 11·4 | 9·9 | 7·9 | 6·7 | 9·9 |
| *Turkey*— | | | | | | | | | | | | | |
| Ankara | 4·3 | 3·8 | 5·4 | 7·0 | 8·6 | 10·8 | 12·5 | 12·1 | 9·6 | 7·7 | 5·0 | 3·2 | 7·5 |
| *Egypt*— | | | | | | | | | | | | | |
| Alexandria | 6·9 | 7·7 | 9·2 | 10·7 | 11·4 | 12·4 | 12·5 | 12·2 | 11·1 | 10·0 | 8·4 | 6·6 | 9·9 |
| Cairo | 7·5 | 8·4 | 9·7 | 10·8 | 11·6 | 12·9 | 12·6 | 12·2 | 11·1 | 10·0 | 8·8 | 7·6 | 10·3 |
| *Kenya*— | | | | | | | | | | | | | |
| Nairobi | 9·3 | 8·2 | 7·6 | 6·5 | 4·5 | 5·0 | 3·6 | 3·6 | 4·5 | 7·1 | 7·2 | 8·7 | 6·3 |
| *Rhodesia*— | | | | | | | | | | | | | |
| Salisbury | 6·5 | 6·3 | 7·1 | 8·3 | 8·1 | 8·5 | 8·3 | 9·3 | 9·7 | 9·3 | 7·6 | 6·3 | 7·9 |

TABLE 10.—Average duration of bright sunshine, hours per day—*continued.*

| Place | Jan. | Feb. | March | April | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. | Year |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Soudan—* | | | | | | | | | | | | | |
| Khartum | 10·6 | 10·8 | 10·7 | 10·8 | 10·1 | 10·0 | 8·9 | 8·9 | 9·7 | 10·4 | 10·9 | 10·7 | 10·2 |
| *South Africa—* | | | | | | | | | | | | | |
| Cape Town | 9·7 | 9·8 | 8·4 | 6·5 | 6·1 | 4·8 | 4·9 | 5·9 | 6·8 | 7·9 | 9·2 | 10·2 | 7·5 |
| *Canada—* | | | | | | | | | | | | | |
| Edmonton | 2·4 | 3·9 | 5·4 | 7·3 | 7·9 | 8·6 | 9·6 | 8·3 | 6·3 | 5·0 | 3·3 | 2·4 | 5·9 |
| Ottawa | 3·1 | 4·3 | 5·1 | 6·3 | 7·0 | 8·1 | 8·4 | 7·9 | 6·0 | 4·4 | 2·8 | 2·4 | 5·5 |
| Toronto | 2·5 | 3·8 | 5·0 | 6·3 | 7·3 | 8·8 | 9·2 | 8·2 | 6·8 | 4·8 | 2·8 | 2·1 | 5·7 |
| Victoria B.C. | 1·9 | 3·0 | 4·8 | 6·3 | 7·2 | 8·0 | 9·9 | 8·8 | 6·6 | 4·0 | 2·2 | 1·5 | 5·3 |
| Winnipeg | 3·3 | 4·7 | 5·4 | 6·8 | 8·1 | 8·3 | 9·3 | 8·4 | 5·9 | 4·2 | 2·8 | 2·5 | 5·8 |
| *United States—* | | | | | | | | | | | | | |
| Charleston | 5·8 | 7·2 | 7·8 | 9·4 | 9·7 | 10·0 | 8·8 | 8·5 | 8·6 | 7·5 | 7·3 | 5·4 | 8·0 |
| Chicago | 4·2 | 5·6 | 6·2 | 7·9 | 9·1 | 10·9 | 10·6 | 9·3 | 7·9 | 6·4 | 4·8 | 3·7 | 7·2 |
| Denver | 6·3 | 7·7 | 7·5 | 8·3 | 8·7 | 10·4 | 9·8 | 9·0 | 8·8 | 7·5 | 6·7 | 5·9 | 8·0 |
| Key West | 7·2 | 9·2 | 9·5 | 10·5 | 9·8 | 10·1 | 9·6 | 9·2 | 8·5 | 7·1 | 7·7 | 7·5 | 8·8 |
| New Orleans | 5·3 | 6·4 | 7·0 | 8·5 | 9·1 | 9·0 | 7·6 | 7·2 | 7·8 | 7·4 | 6·4 | 4·4 | 7·2 |
| New York | 4·7 | 6·8 | 7·0 | 8·2 | 8·8 | 9·8 | 9·3 | 8·4 | 8·0 | 6·7 | 5·5 | 4·6 | 7·3 |
| Portland, Oregon | 2·2 | 3·8 | 4·8 | 7·0 | 7·5 | 9·4 | 10·1 | 9·1 | 6·8 | 4·4 | 2·5 | 2·0 | 5·9 |
| St. Louis | 4·7 | 5·8 | 6·4 | 7·9 | 9·1 | 10·1 | 10·1 | 9·0 | 8·3 | 6·8 | 5·8 | 4·2 | 7·4 |
| Salt Lake City | 4·4 | 5·7 | 6·8 | 8·8 | 9·7 | 11·9 | 11·4 | 10·4 | 9·5 | 7·4 | 5·7 | 4·0 | 8·0 |
| San Francisco | 5·2 | 6·4 | 7·5 | 9·2 | 9·7 | 11·0 | 9·8 | 8·4 | 9·0 | 7·8 | 6·2 | 5·4 | 8·0 |
| Washington D.C. | 4·5 | 6·2 | 6·5 | 7·9 | 8·6 | 9·3 | 9·0 | 8·0 | 7·7 | 6·7 | 5·6 | 4·5 | 7·0 |
| *Panama—* | | | | | | | | | | | | | |
| Balboa Hts. | 8·9 | 8·6 | 8·3 | 6·6 | 4·4 | 4·3 | 4·8 | 4·2 | 4·8 | 4·5 | 4·6 | 7·0 | 5·9 |
| *Argentine—* | | | | | | | | | | | | | |
| Buenos Aires | 9·2 | 8·5 | 7·5 | 6·8 | 4·9 | 3·5 | 3·8 | 5·2 | 6·0 | 6·8 | 8·1 | 8·5 | 6·6 |
| Cordoba | 8·9 | 8·4 | 7·4 | 6·7 | 6·1 | 5·7 | 5·8 | 6·9 | 7·6 | 7·6 | 8·9 | 9·2 | 7·5 |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Bolivia*— | | | | | | | | | | | | | |
| La Paz | 4·5 | 4·3 | 5·4 | 7·0 | 9·0 | 10·8 | 9·1 | 8·3 | 8·3 | 7·5 | 6·2 | 5·7 | 7·1 |
| *Chile*— | | | | | | | | | | | | | |
| Santiago | 10·7 | 11·0 | 9·3 | 7·7 | 5·1 | 4·1 | 4·5 | 5·2 | 5·5 | 7·3 | 9·0 | 10·8 | 7·5 |
| *Ecuador*— | | | | | | | | | | | | | |
| Quito | 5·7 | 4·4 | 4·0 | 4·5 | 5·8 | 6·3 | 7·9 | 7·8 | 6·9 | 5·6 | 5·9 | 7·3 | 6·0 |
| *Guiana*— | | | | | | | | | | | | | |
| Georgetown | 6·2 | 6·7 | 6·3 | 6·6 | 5·9 | 5·7 | 7·0 | 7·7 | 8·3 | 7·8 | 7·1 | 6·0 | 6·8 |
| *Venezuela*— | | | | | | | | | | | | | |
| Caracas | 7·6 | 7·8 | 7·5 | 6·4 | 6·4 | 6·4 | 7·3 | 7·4 | 7·2 | 6·8 | 6·9 | 6·7 | 7·0 |
| *Australia*— | | | | | | | | | | | | | |
| Adelaide | 10·0 | 9·3 | 7·7 | 6·0 | 4·8 | 4·1 | 4·4 | 5·2 | 6·2 | 7·3 | 8·8 | 9·7 | 7·0 |
| Brisbane | 7·5 | 7·5 | 7·0 | 7·0 | 6·6 | 6·1 | 6·8 | 7·7 | 8·0 | 8·3 | 8·2 | 8·1 | 7·4 |
| Canberra | 7·6 | 6·9 | 7·0 | 6·4 | 5·1 | 4·2 | 4·6 | 5·6 | 6·8 | 7·5 | 7·5 | 7·4 | 6·4 |
| Hobart | 7·6 | 7·0 | 6·4 | 4·7 | 4·6 | 3·9 | 4·2 | 5·1 | 5·8 | 6·2 | 7·4 | 7·0 | 5·8 |
| Melbourne | 8·3 | 8·4 | 6·6 | 5·3 | 4·5 | 3·7 | 4·2 | 4·9 | 5·7 | 6·4 | 7·7 | 7·9 | 6·1 |
| Perth | 10·4 | 9·7 | 8·7 | 7·3 | 5·6 | 4·8 | 5·3 | 6·0 | 6·9 | 7·8 | 9·6 | 10·0 | 7·7 |
| Sydney | 7·3 | 7·2 | 6·5 | 6·2 | 5·7 | 5·3 | 6·0 | 7·1 | 7·4 | 7·8 | 7·8 | 7·2 | 6·8 |
| *New Zealand*— | | | | | | | | | | | | | |
| Auckland | 7·3 | 6·7 | 5·9 | 4·9 | 4·2 | 3·9 | 3·9 | 4·9 | 5·0 | 5·6 | 6·4 | 6·9 | 5·5 |
| Christchurch | 6·8 | 6·7 | 5·4 | 4·3 | 4·3 | 3·2 | 4·0 | 4·6 | 5·4 | 6·1 | 7·0 | 6·4 | 5·3 |
| Wellington | 7·8 | 6·9 | 6·4 | 5·2 | 4·5 | 3·5 | 3·6 | 4·5 | 5·4 | 6·3 | 7·4 | 7·5 | 5·7 |
| *Iceland*— | | | | | | | | | | | | | |
| Reykjavik | 0·5 | 1·9 | 2·5 | 5·5 | 7·1 | 8·6 | 6·5 | 5·8 | 4·6 | 3·1 | 1·0 | 0·1 | 3·9 |
| *Philippines*— | | | | | | | | | | | | | |
| Manila | 5·7 | 6·7 | 7·3 | 8·4 | 7·1 | 5·3 | 4·3 | 4·3 | 4·4 | 5·1 | 5·1 | 4·9 | 5·8 |
| *West Indies*— | | | | | | | | | | | | | |
| Bermuda | 4·9 | 5·3 | 6·2 | 7·2 | 8·1 | 8·8 | 10·0 | 8·9 | 8·0 | 6·5 | 5·7 | 5·1 | 7·1 |
| Kingston, Jamaica | 7·9 | 7·8 | 8·6 | 7·1 | 7·0 | 7·5 | 7·9 | 8·3 | 7·1 | 6·2 | 6·2 | 7·6 | 7·4 |

area per unit volume of interior space; (4) the temperature and wind-speed of the outside air.

(1) Other things being equal, the insulating property of a wall is proportional to its thickness. Hence, with ordinary building materials the thickness of the walls must be greater the lower the winter temperature. While in southern England, Belgium and Holland a thickness of 9 inches generally gives sufficient insulation, 10 inches is the minimum in Western Germany, 15 inches in Central and Eastern Germany, 20 inches in Lithuania and Poland, and 28–30 inches in Russia. A rough rule is that the thickness should be 9 inches if the mean temperature of the coldest month is 34° F. or more, and should increase by 1 inch for every degree by which the mean temperature of the coldest month falls below 34° F. In windy situations, however, the thickness needs to be increased, hence the generally thick walls of upland farmhouses.

(2) For equal thickness the lower the heat conductivity of the material the better the insulation. Air is one of the best insulators provided that free circulation is prevented; hence dry, porous materials are better than close-grained stone; metal is the worst of all. The following figures give approximately the heat required to maintain a temperature difference of 50° F. between the inside and outside of a wall 10 inches thick, expressed in B.T.U. per hour per square foot of wall area:—

*Material of Wall*

| | | | |
|---|---|---|---|
| Air Space (Still air) | 0·8 | Asbestos | 4 |
| Felt | 1·3 | Cement | 10 |
| Dry Sandstone | 1·9 | Iron | 1600 |

The insulating power of porous material is destroyed if the pores are filled with water, so that a waterproofed surface is necessary, especially on the weather side. Loss of heat through saturated walls is many times (5–20) that through dry, porous walls. Wet walls are also cooled by evaporation, and for this reason also it is desirable that walls should shed rain-water quickly instead of absorbing it. Double walls separated by an air space require provision against free circulation of air, otherwise the space will be filled with cold air which will cool and damp the internal walls, and ties must be arranged so as not to lead moisture inwards.

A great deal of heat is lost through windows. This loss can

be minimised by making windows small as well as tight-fitting; if large windows are required to give good lighting in climates with very cold winters they should be double, separated by an air-space.

In most buildings the hottest air collects under the roofs and ceilings, and as the wind speed is also greatest at roof level the roof is the greatest source of heat loss. Hence insulation of the roofs, which is often neglected, is especially important.

(3) The loss of heat depends on the surface area, which depends on the square of the linear dimensions, while the volume depends on the cube. Hence, to a first approximation doubling the linear scale of a building halves the heat required for heating per cubic yard of interior space. However, as the wind speed increases with height above the ground (see p. 34), this gain is partly counterbalanced by increased loss from the upper floors. The increase of wind speed with height is greatest at night, when the air is coldest, so that the upper rooms of high buildings in winter tend to be cold in the morning. The most economical arrangement for heating is probably long, low buildings with well-insulated roofs, arranged parallel with the prevailing wind, but with some form of wind-break to prevent the uninterrupted sweep of the winds between the buildings.

(4) Still air conducts heat very slowly, but the loss of heat is greatly increased by even a moderate wind. Outdoor air is very rarely completely calm; even if there is no natural breeze, convection from walls and roofs of buildings introduces some movement. As it passes a large building the air is warmed slightly, but the more rapid the movement the smaller the warming. The cooling effect is roughly proportional to the square root of the wind speed. In cold air with a wind of 12 m.p.h. the loss of heat is about three times the loss at the same temperature in calm air. Allowance has to be made for the different temperatures of winds from different directions; the coldest winds in winter are, generally speaking, those which have had the longest passage over land, and come from higher latitudes. In London, for example, in December to February, the mean temperature of east and north-east winds which come from high latitudes in Europe is about 30° F. Winds from north, which blow mostly over cold oceans, have a mean temperature of about 34°, and those from north-west about 38°. Westerly winds which came originally from high latitudes but have had

a long passage over the relatively warm Atlantic have a mean of about 42°, and south-westerly winds reach 48° and provide warm, muggy conditions. On the other hand, the cold, dry south-east winds which blow across France are much colder. averaging only 39° F. The temperature depends on the origin of the air as well as the direction of the wind (J. E. Belasco, 1945).

## LIGHTING

The unit of illumination is the *lux*, which is defined as the direct illumination on a point one metre from a point source of light of one candle-power. One lux equals 0·093 foot-candles. In the open, except in conditions of thick fog or very heavy cloud, there is always enough illumination so long as the sun is above the horizon. On cloudless days the direct illumination from the sun well above the horizon exceeds 10,000 lux. In moderately cloudy weather the illumination is almost directly proportional to the height of the sun, and amounts to about

TABLE 11.—Average length of day, sunrise to sunset, hours and tenths.

| Latitude | Jan. | Feb. | March | April | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 66° N. | 4·4 | 8·0 | 11·5 | 15·2 | 19·0 | 22·9 | 20·6 | 16·8 | 13·1 | 9·6 | 5·8 | 2·9 |
| 64° | 5·4 | 8·4 | 11·6 | 14·9 | 18·1 | 20·5 | 19·5 | 16·3 | 13·0 | 9·8 | 6·5 | 4·3 |
| 62° | 6·1 | 8·7 | 11·6 | 14·7 | 17·5 | 19·4 | 18·6 | 15·9 | 12·9 | 10·0 | 7·0 | 5·2 |
| 60° | 6·7 | 9·0 | 11·7 | 14·5 | 17·0 | 18·6 | 17·9 | 15·6 | 12·9 | 10·1 | 7·5 | 5·9 |
| 58° | 7·2 | 9·3 | 11·7 | 14·3 | 16·6 | 17·9 | 17·3 | 15·2 | 12·8 | 10·3 | 7·9 | 6·5 |
| 56° | 7·6 | 9·5 | 11·8 | 14·1 | 16·2 | 17·4 | 16·9 | 15·0 | 12·7 | 10·4 | 8·2 | 7·0 |
| 54° | 8·0 | 9·7 | 11·8 | 13·9 | 15·9 | 17·0 | 16·5 | 14·8 | 12·7 | 10·5 | 8·5 | 7·4 |
| 52° | 8·3 | 9·8 | 11·8 | 13·8 | 15·6 | 16·6 | 16·1 | 14·6 | 12·7 | 10·6 | 8·8 | 7·8 |
| 50° | 8·6 | 10·0 | 11·8 | 13·7 | 15·3 | 16·2 | 15·8 | 14·4 | 12·6 | 10·7 | 9·0 | 8·1 |
| 45° | 9·1 | 10·3 | 11·8 | 13·4 | 14·8 | 15·5 | 15·2 | 14·0 | 12·5 | 10·9 | 9·5 | 8·8 |
| 40° | 9·6 | 10·6 | 11·8 | 13·2 | 14·3 | 14·9 | 14·7 | 13·7 | 12·4 | 11·1 | 10·0 | 9·3 |
| 35° | 10·0 | 10·9 | 11·9 | 13·0 | 13·9 | 14·4 | 14·2 | 13·4 | 12·4 | 11·3 | 10·3 | 9·8 |
| 30° | 10·4 | 11·1 | 11·9 | 12·8 | 13·6 | 14·0 | 13·8 | 13·2 | 12·3 | 11·4 | 10·6 | 10·2 |
| 25° | 10·7 | 11·3 | 12·0 | 12·7 | 13·3 | 13·6 | 13·5 | 13·0 | 12·3 | 11·5 | 10·9 | 10·6 |
| 20° | 11·1 | 11·5 | 12·0 | 12·6 | 13·1 | 13·3 | 13·2 | 12·8 | 12·3 | 11·7 | 11·2 | 10·9 |
| 15° | 11·3 | 11·6 | 12·0 | 12·5 | 12·8 | 13·0 | 12·9 | 12·6 | 12·2 | 11·8 | 11·4 | 11·2 |
| 10° | 11·6 | 11·8 | 12·1 | 12·3 | 12·6 | 12·7 | 12·6 | 12·5 | 12·2 | 11·9 | 11·7 | 11·5 |
| 5° N. | 11·9 | 12·0 | 12·1 | 12·2 | 12·3 | 12·4 | 12·4 | 12·3 | 12·2 | 12·0 | 11·9 | 11·8 |
| 0° | 12·1 | 12·1 | 12·1 | 12·1 | 12·1 | 12·1 | 12·1 | 12·1 | 12·1 | 12·1 | 12·1 | 12·1 |
| 5° S. | 12·4 | 12·3 | 12·1 | 12·0 | 11·9 | 11·8 | 11·9 | 11·9 | 12·1 | 12·2 | 12·3 | 12·4 |
| 10° | 12·6 | 12·4 | 12·2 | 11·9 | 11·7 | 11·5 | 11·6 | 11·8 | 12·0 | 12·3 | 12·6 | 12·7 |
| 15° | 12·9 | 12·6 | 12·2 | 11·7 | 11·4 | 11·2 | 11·3 | 11·6 | 12·0 | 12·4 | 12·8 | 13·0 |
| 20° | 13·2 | 12·7 | 12·2 | 11·6 | 11·2 | 10·9 | 11·0 | 11·4 | 12.0 | 12·5 | 13·0 | 13·3 |
| 25° | 13·5 | 12·9 | 12·2 | 11·5 | 10·9 | 10·6 | 10·7 | 11·2 | 11·9 | 12·6 | 13·3 | 13·6 |
| 30° | 13·8 | 13·1 | 12·2 | 11·3 | 10·6 | 10·2 | 10·4 | 11·0 | 11·9 | 12·7 | 13·6 | 14·0 |
| 35° | 14·2 | 13·3 | 12·3 | 11·2 | 10·3 | 9·8 | 10·0 | 10·8 | 11·8 | 12·9 | 13·9 | 14·4 |
| 40° | 14·6 | 13·6 | 12·3 | 11·0 | 9·9 | 9·3 | 9·6 | 10·5 | 11·8 | 13·1 | 14·3 | 14·9 |
| 45° | 15·1 | 13·9 | 12·4 | 10·8 | 9·5 | 8·8 | 9·1 | 10·2 | 11·7 | 13·3 | 14·7 | 15·5 |
| 50° | 15·8 | 14·3 | 12·4 | 10·6 | 9·0 | 8·1 | 8·5 | 9·8 | 11·6 | 13·5 | 15·2 | 16·2 |
| 52° | 16·1 | 14·4 | 12·5 | 10·5 | 8·7 | 7·8 | 8·2 | 9·7 | 11·6 | 13·6 | 15·5 | 16·5 |
| 54° | 16·4 | 14·6 | 12·5 | 10·3 | 8·4 | 7·4 | 7·8 | 9·5 | 11·5 | 13·7 | 15·7 | 16·9 |
| 56° | 16·8 | 14·9 | 12·5 | 10·2 | 8·1 | 7·0 | 7·5 | 9·3 | 11·5 | 13·9 | 16·1 | 17·4 |
| 58° | 17·2 | 15·1 | 12·6 | 10·1 | 7·8 | 6·5 | 7·0 | 9·0 | 11·5 | 14·0 | 16·4 | 17·9 |
| 60° S. | 17·8 | 15·3 | 12·6 | 9·9 | 7·4 | 5·9 | 6·5 | 8·8 | 11·4 | 14·2 | 16·9 | 18·6 |

700 lux for every 10° of solar altitude. The effect of cloud or obstacles is felt chiefly before sunrise and after sunset.

*Civil twilight* covers the periods before sunrise and after sunset during which there is enough light for ordinary outdoor occupations. In Britain it officially begins and ends when the sun is 6° below the horizon, and its duration in different latitudes according to this definition is tabulated in the abridged edition of the *Nautical Almanac* (London, H.M.S.O., annually). Its duration depends on the angle which the path of the sun makes with the horizon; it is shorter in low than in high latitudes, and in all latitudes it is shortest at the equinoxes and longest at the solstices.

The duration of evening twilight in different latitudes of the northern hemisphere is as follows:—

| Latitude | Duration of Evening Twilight, minutes. | | | |
|---|---|---|---|---|
| | March 21 | June 21 | Sept. 21 | Dec. 21 |
| 0 | 21 | 22 | 21 | 22 |
| 30 | 24 | 27 | 24 | 27 |
| 40 | 27 | 32 | 28 | 30 |
| 50 | 32 | 44 | 33 | 38 |
| 54 | 35 | 54 | 36 | 43 |
| 58 | 39 | 1 h. 16 m. | 40 | 51 |
| 62 | 44 | — | 46 | 1 h. 5 m. |
| 66 | 51 | — | 53 | 1 h. 40 m. |

North of 60° N. twilight at midsummer lasts all night. In practice the duration of twilight depends also on cloud conditions and on the obstruction of the horizon, particularly towards the rising or setting sun. In an open situation with a clear sky it is possible to read out of doors until the sun is about $6\frac{1}{2}$° below the horizon.

Fig. 10 shows, on the left, the illumination in an open space with different distances of the sun below the horizon on days of clear sky, overcast or foggy days, and in heavy rain; and, on the right the effect of buildings on either side, as in a street. In a street running east and west the twilight illumination is about 15 per cent. greater, and in a street running north and south about 20 per cent. less than the average shown in the figure.

A snow cover on the ground increases the illumination by about 20 per cent.

Inside a building the illumination is very much less than in the open, the ratio depending on the size of the windows, the direction in which they face, the "skyline" visible from the

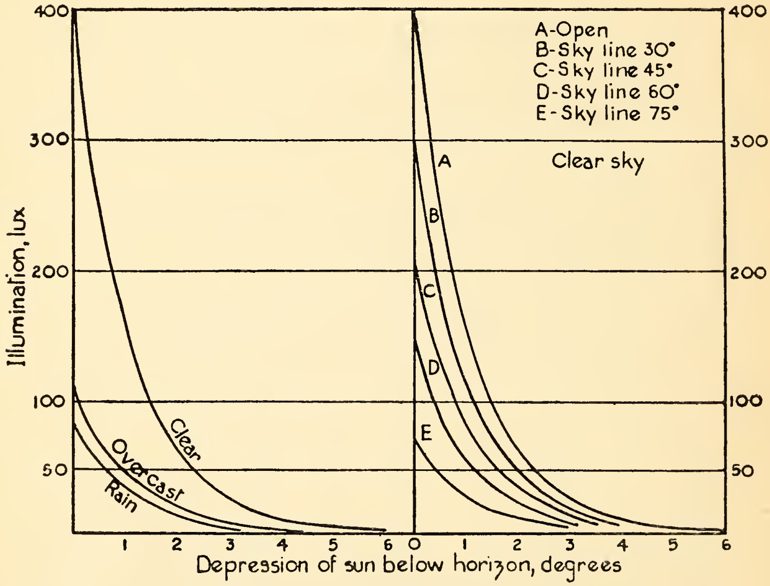


Fig. 10.—Effect of cloud and sky-line on illumination.

windows, and, of course, the position in the room. This point is discussed in Chapter XI.

## PURITY OF AIR

A good supply of clean air is essential both for living and working conditions. Natural ventilation depends on the wind, but wind also carries impurities from sources of pollution, such as chimneys, and raises dust. Dust is most troublesome near ground level, especially at corners, while solid particles and gases due to combustion are most abundant at the general roof level. The air is in general cleanest at about three-quarters of the height from the ground to the general roof level, but on the lee side of buildings eddies are apt to carry pollution downwards. If clean air is necessary for manufacturing processes,

as with such products as confectionery and cosmetics, the site should be to windward of the main sources of pollution. In Britain this means on the south-west side of large towns; the Bourneville works, for example, are to the south-west of Birmingham. Even in such situations, however, the air is contaminated when the wind blows from the town. Vegetation is very effective in cleaning air, and a belt of trees a short distance to windward (or in the direction of sources of pollution) is a valuable precaution. Atmospheric pollution is discussed further in Chapter IX.

Atmospheric impurities have a damaging effect on the structure of buildings. A great deal of gaseous acid impurity is brought down by rain, and if the rain penetrates the walls it carries the impurities with it and the acids attack the lime in the walls. When the walls dry out these salts are brought to the surface and form a hard crust. Where this crust is broken, holes develop in the softened material below. To avoid this trouble it is necessary to get the water away from the walls quickly by means of a smooth, impervious covering. Atmospheric impurities also attack metals; iron, for example, rusts more quickly in the presence of sulphur dioxide than in pure air, and still more quickly when solid carbonaceous particles are present (see Chapter IX).

## LOCAL SITUATION IN REGARD TO FROST, RAIN, SNOW, ETC.

*Frost and fog.*—The local distribution of frost and fog in relation to topography was discussed in Chapter I. A combination of frost and fog is bad from all points of view—health, expense of lighting and heating, damage to buildings, clothes and products in course of manufacture, and delay in transport, The best situation is in the middle third of a gentle southerly slope from a narrow ridge, with a good air drainage, but below the strong winds and cloud of the hill tops. A site on the side of a plateau is less favourable because there is a greater supply of cold air from the more extensive surface. Frost and fog develop at night in hollows and in valleys in which the natural air drainage is obstructed. The obstruction may be a narrowing of the valley, a railway embankment or even a belt of trees, and there is likely to be a sharp frost and fog line at or a little above the top of the obstruction. Hence, if a site in such a

valley is under consideration a survey of such obstacles to free air flow should be made.

A striking example of the effect of a narrow valley in creating a frost-hollow, aided to some extent by a railway embankment, is described by E. L. Hawke (1944) from near Rickmansworth in Hertfordshire. He sums up by quoting figures to show that the night climate of this low-level Hertfordshire valley is almost identical with that of Braemar, at a height of 1,110 feet in Aberdeenshire, and Moor House, 1,840 feet up in the northern Pennines. A still more remarkable and instructive example from Austria is quoted by Hawke (1946) in a chatty article on frost-hollows in general.

Even on slopes situations differ as regards liability to frost. The cold air flowing downwards from the hills follows the line of least resistance and is readily diverted by obstacles. These may be so placed as to concentrate the air flow in well-defined channels, where on clear nights ground and buildings are exposed to a strong, cold breeze. Such situations can usually be recognised from a study of the ground, and it may be possible to divert the air by planting trees or building walls *obliquely* across the path of the air.

The disadvantages of hollows are mainly limited to the night and early morning; it is only during severe cold spells in winter that frost and fog persist all day. In sunny weather hollows are bright and warm during the day, though the sun soon goes off. Hence, such a hollow may not be unsuitable for buildings such as offices which are not in use at night, for the cold of early morning is partly counterbalanced by shelter against wind and driving rain. Frost hollows are bad sites for residences, gardens and orchards.

Frost damages walls and roads by "exfoliation" or flaking off of the surface. The important factor is not so much the degree of cold as the frequency with which the temperature oscillates about the freezing-point. This can be calculated from the difference between the number of days of screen frost (*i.e.* days on which the air temperature in the shade falls below 32° F. at night) and the number of ice-days, or days on which the temperature does not rise above freezing-point at any time. These figures can be obtained from the Meteorological Service. In Britain ice-days are rare; data collected by the Meteorological Office show that the average number is only one or two

a winter near the coast, rising to four at moderate heights inland in England and seven in southern Scotland; on higher ground the number is greater. Frost days, on the other hand, vary from about ten on the coasts of Cornwall and Wales to 40 or 50 over most of England (70 in the lowlands of the eastern interior) and 100 over much of Scotland. The number of frost days depends very much on the local situation. In colder regions, such as central and eastern Europe, Siberia and much of North America, ice-days are very frequent in winter, and the risk of frost damage probably does not differ much from that in Britain.

An important factor in design is the depth to which frost penetrates in winter. This depends on three factors: (1) the duration and severity of the period with mean temperature below 32° F.; (2) the presence and thickness of a snow cover; and (3) the nature of the soil. (1) The depth of penetration of frost may be taken as roughly proportional to the square root of the accumulated temperature below freezing-point. The latter figure can be found by taking all months with mean temperatures below 32° F. and adding up the deficits. For practical purposes, since the duration of the winter is roughly proportional to its severity, the depth of frost penetration in *bare ground* may be taken as very roughly one to two feet when the temperature of the coldest month is about 5° F. below freezing-point. In the great frost of 1895, for example, the mean air temperature of the period from 26th January to 19th February was about 26° F. in London, and the lowest readings of the earth thermometers at 1 foot depth ranged from 28° to 32°. Water mains were frozen at considerably greater depths, generally 2–3 feet and even more, but this was attributed to the fact that, close by, the pipes were near the surface so that the water was already practically at freezing-point, and that heat conduction along iron pipes lowered the temperature of the mains even further.

In countries with cold winters frost shortens the period during which building can be carried on owing to its effect on cement and mortar. In central Europe the risk of frost is practically limited to the period with mean daily temperature below 50° F., but urgent work can be carried on by the use of special mixtures or by electrical heating. According to B. Hrudicka (1937–8) the energy needed for the latter is one Kw.hour per

cubic metre for each Centigrade degree by which the air temperature falls below 0° C. or 32° F.

Days on which the temperature falls below 32° F. are termed "ice-days" or "frost-days." In an ice-day frost persists all day. In a frost-day which is not an ice-day temperature rises above freezing-point at some time during the day. In Britain it is estimated that following a morning with frost, on the average about one-third of the working day between 7 a.m. and 5 p.m. has a temperature below 32° F. Consequently the loss of working days due to frost is about one-third of the number of frost-days, less allowance for Sundays and holidays.

(2) Loose snow is a good insulator, and a thick cover of snow prevents the temperature of the ground beneath from falling much below 32° F. The conductivity of new snow is three to four times that of air, roughly half that of ordinary compacted soil, and equal to or slightly greater than that of loose soil or loose sand. Thus the insulating effect of a layer of loose, new snow 1 foot deep is roughly equivalent to that of 2 feet of dry sub-soil and to a much greater thickness of rock. As the snow becomes compacted, however, its thermal conductivity increases, and for old snow it is three or four times that of new snow.

(3) The insulating effect of soil depends almost entirely on the amount of air which it holds per unit volume. The conductivity rises rapidly as this is replaced by water or ice. Hence the saturation of soil greatly increases the depth of freezing.

When water freezes it expands, and a serious effect of the freezing of wet ground is the "heaving" of the soil, which may cause cracks in buildings. To avoid this it is necessary to extend the foundations below the depth to which the soil is likely to freeze.

*Rainfall* increases with height above sea-level, especially on windward slopes. In Britain the increase is at the rate of 2 or 3 per cent. per hundred feet in the moderately hilly country of the south and midlands, and 4 per cent. in mountain regions such as north Wales. For example, the average rainfall is 24·5 inches a year at Camden Square (110 feet) and 26·2 inches at Golder's Hill Park (350 feet), an increase of nearly 3 per cent. per hundred feet. Except in very hilly country, however, these local differences of rainfall are not of great importance. In some parts of the world there is a very great

difference between the windward and leeward sides of the hills, and if the wind blows steadily from the same direction this fact is of great economic importance. In tropical regions like Hawaii or Southern India the rainfall may exceed 100 inches a year on the windward slopes of the hills fronting the ocean, and fall to only about 30 inches a short distance away on the leeward side. The former is too wet for settlement, the latter too dry, unless water can be obtained from across the summit. Rain causes loss of time in building operations. The *duration* of rainfall in Britain is measured as the time during which rain is falling at the rate of 0·004 inch (0·1 mm.) or more per hour, and averages about 600 hours a year in the lowlands of the west and north, and 500 hours a year in the Midlands and London. Corresponding figures are difficult to obtain for other countries. In the temperate regions between about latitudes 45° and 60° N. the duration of rainfall may be taken as roughly proportional to the number of raindays. In lower latitudes the rainfall is heavier and the duration for the same amount of rain is correspondingly less.

As a guide to the effect of rainfall on ordinary outdoor occupations the following scale of rainfall intensities is suggested (amounts in inches):—

TABLE 13.—Scale of rainfall intensity.

| Intensity | 5 mins. | 30 mins. | 1 hour | 2 hours | 1 day |
|---|---|---|---|---|---|
| 1. Barely perceptible | — | below 0·002 | below 0·004 | below 0·004 | below 0·005 |
| 2. Very light . | below 0·004 | 0·002–0·01 | 0·004–0·015 | 0·004–0·02 | 0·005–0·04 |
| 3. Light . . | 0·004–0·01 | 0·01–0·03 | 0·015–0·04 | 0·02–0·05 | 0·04–0·1 |
| 4. Moderate . . | 0·01–0·03 | 0·03–0·1 | 0·04–0·15 | 0·05–0·2 | 0·1–0·4 |
| 5. Moderately heavy | 0·03–0·08 | 0·1–0·3 | 0·15–0·4 | 0·2–0·5 | 0·4–1·0 |
| 6. Heavy . . | 0·08–0·2 | 0·3–0·75 | 0·4–1·0 | 0·5–1·25 | 1·0–3·0 |
| 7. Very heavy . | 0·2–0·4 | 0·75–1·5 | 1·0–2·0 | 1·25–2·5 | 3·0–6·0 |
| 8. Torrential . | 0·4–0·8 | 1·5–2·5 | 2·0–3·5 | 2·5–5·0 | 6·0–12·0 |
| 9. Phenomenal . | above 0·8 | above 2·5 | above 3·5 | above 5·0 | above 12·0 |

Falls up to and including "Light" do not interfere with ordinary outdoor activities; in Britain these account for about a quarter of the total duration of rain. "Moderate" falls interfere with but do not necessarily prevent outdoor work. "Moderately heavy" falls prevent outside activities, "Very heavy" falls cause minor flooding and "Torrential" falls cause

extensive flooding. But the effect of a given fall varies very much according to the normal rainfall of the district. Thus 10 inches in a day has never been recorded in Britain (9·56 inches was recorded at Bruton, Somerset, on 28th June 1917), but at Cherrapunji, India, a fall of 10 inches would pass without notice. Extreme rainfalls are discussed in Chapter X.

The terminal velocity of raindrops falling in still air is approximately as follows:—

| | | | | | | |
|---|---|---|---|---|---|---|
| Diameter of drop, inch . . | 0·02 | 0·05 | 0·10 | 0·15 | 0·20 | 0·3 |
| Velocity, feet/second . . | 13 | 16 | 24 | 28 | 30 | 30 |

Raindrops cannot grow to a greater diameter than 0·3 inch because, owing to the resistance of the air, at that size they flatten out and break up into smaller drops. The inclined velocity of a drop carried by the wind is the square root of the sum of squares of wind speed and terminal velocity.

*Snow* is important in building design in certain regions because of the additional load which it places on roofs. The snowiest parts of the world are the mountain region from Alaska to the northern United States, especially British Columbia and north-eastern Japan; any mountain region facing winds off the sea in a cold climate is liable to heavy falls of snow. The weight of freshly fallen snow varies according to its "fluffiness"; an average figure is about 6½ lbs. per cubic foot. As the snow becomes compacted its weight per cubic foot increases, and in old snow may be as much as 30 lbs. In the coastal ranges of western North America the weight of snow on level surfaces may be as much as 250 lbs. per square foot. roughly a ton per square yard. In these regions houses are always built with steep roofs, which allow the snow to slide off; a slope of 60° does not carry snow. In the north-eastern United States and eastern Canada the snow cover on flat roofs may reach a weight of 50 lbs. per square foot; in New York it is customary to allow for 40 lbs. In Britain and western Europe the maximum depth of undrifted snow on level ground rarely exceeds 2 feet, equivalent to about 13 lbs. per square foot. As, however, owing to drifting the depth of snow may be locally greater it would seem desirable to allow for a snow load of at least 20 lbs. per square foot on large flat roofs. Where the local topography causes the snow to pile up in drifts the thickness may be much greater, and hill country is especially liable to deep drifts. Two or three

feet of snow may seem a trivial addition to the weight of a roof, but it has sufficed to cause the collapse of large buildings. A notable example was the Knickerbocker theatre disaster in Washington in 1922.

## WIND

Wind speed and direction must be taken into consideration both in the siting and construction of all buildings. Especially important are wind pressure and the effect of the wind in distributing smoke and noxious fumes. To appreciate the effects

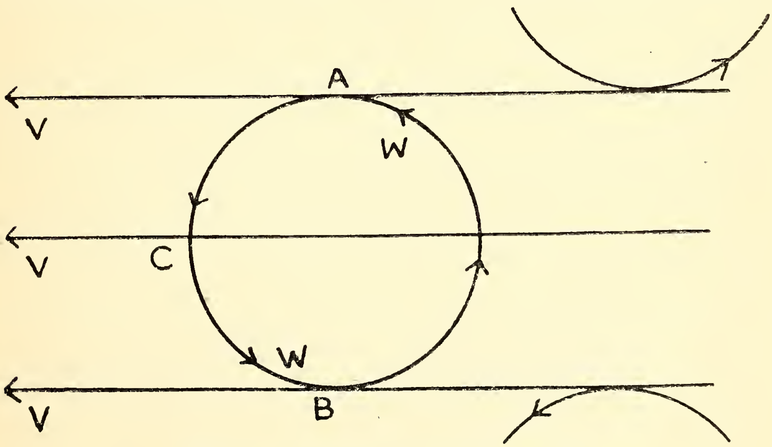


Fig. 11.—Illustration of turbulence.

of wind it is necessary to understand something of wind structure. With very few exceptions wind does not consist of a regular flow of air like a smoothly flowing river. Over open, fairly level country it is made up of a series of whirls or eddies, which travel along with the general stream of air. Whenever an eddy passes, the wind at any point changes in direction or speed, usually both.

In Fig. 11 the straight arrows represent the general wind, with speed V. The circle represents an eddy blowing in an anti-clockwise direction with speed W. As the eddy passes over point A the two speeds V and W are added together, and the wind momentarily blows with speed V+W. This is a *gust.* At the point B, on the other hand, the two speeds will partly cancel out, and the wind speed will momentarily drop to V—W; this is a *lull.* At C the wind speed does not change much, but its

direction swings first to the left and then to the right. Since the distribution of eddies is quite irregular and they completely fill the wind stream, the result at any one place is a continuous succession of gusts and lulls and small changes of direction. The diameter of an eddy is generally between 50 and 100 feet, increasing with the speed of the general current of air, so that eddies, and consequently gusts and lulls, follow one another at intervals of a few seconds, averaging about seven seconds. A wind stream made up of such eddies is said to be *turbulent*.

The wind recorder in use at official stations in Britain, the Dines Pressure-tube anemometer, is able to follow these rapid fluctuations so that the trace of the recording pen shows a broad band of nearly vertical lines. The instrument possesses some inertia, of course, and the gust velocities which it records are averages over about two seconds. An example is shown in Fig. 12, reproduced by courtesy of the Air Ministry.

The tops of the velocity lines represent gusts and the bottoms lulls. The width of the band of lines, or the range of wind speed between gusts and lulls is a measure of the gustiness of the wind. Other examples representing a variety of exposures are given by E. Gold (1936).

The gustiness with winds from the same direction at any one place is roughly proportional to the average wind speed and is measured by the "gustiness factor" G, which is the ratio of the average difference between the gusts and lulls to the average mean speed. For example, in a very open situation at Spurn Head a typical record shows an average wind velocity of 25 m.p.h. with gusts of 30 m.p.h. and lulls of 20 m.p.h. The gustiness factor is 10/25 or 0·4. On the other hand, an anemometer exposed on the roof of the Science Museum, London, with an average wind speed of 20 m.p.h. had gusts of 40 m.p.h. and lulls falling almost to calm, a gustiness factor of 2. At a height of 33 feet the gustiness factor is 0·3 or 0·4 on flat islands and about 0·5 on the coast with winds blowing off the sea; inland it is greater, depending on the nature of the country. Probably an average value of 0·5–1·0 would be appropriate for good open situations, rising to 1·5 in sites surrounded by trees or high buildings. The factor decreases with height, *i.e.* the wind becomes smoother the higher it is above the ground. It is greatest in the afternoon and least in the early morning, when it is only half to two-thirds as great.

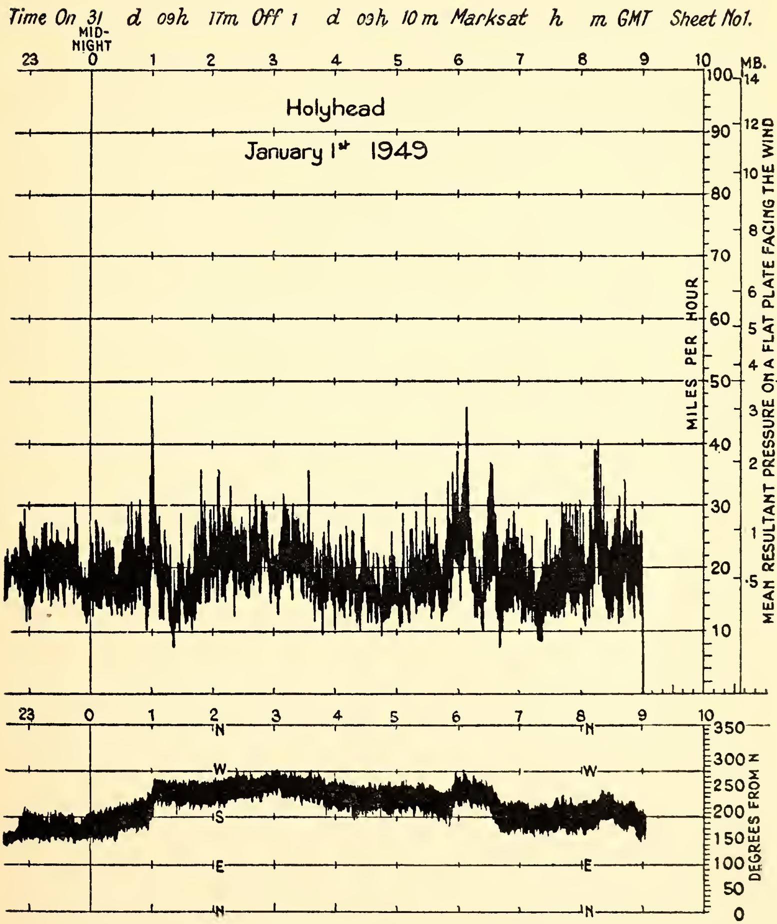


Fig. 12.—Specimen of anemogram.

The range of wind direction over short intervals of time also depends on the gustiness. With a small gustiness factor the wind varies only a few degrees; the extreme range over an hour might be between SW. and WSW. With a high gustiness factor the range of direction is much greater, between say S. and WNW. In a very turbulent situation, such as the lee of a row of houses, the wind may blow from all round the compass.

An anemometer records only the horizontal wind, but there are similar variations in the vertical movement. This can easily be seen by watching the smoke from a factory chimney, which starts as a thin stream, expanding downwind both sideways and up-and-down, to form a cone with horizontal axis, until the smoke becomes too thin to be seen.

In addition to the constant succession of gusts and lulls, on some days there are occasional periods of a few minutes when the wind rises to a peak velocity in about ten seconds and falls off again, generally more gradually over a minute or more; the peak velocity lasts for only about two seconds. These are convectional eddies and may occur simultaneously along a line hundreds of feet wide. They are known as *squalls* and may do a great deal of damage. These are discussed in Chapter X.

The general structure of the wind described above is modified when it meets obstacles such as steep hills or buildings.

*Wind pressure on buildings.*—When the wind encounters a building it presses on the windward face and exerts a force directed towards the interior of the building. On the leeward face the air is sucked away by the wind currents passing overhead and on each side, and a partial vacuum is formed which exercises a suction effect; on this side therefore the force on the walls is directed outwards.

The air piled up against the windward face escapes by passing over the roof; with isolated buildings the air also flows past on either side. Owing to its momentum the air blowing up the face of the building cannot flatten out immediately, and there is also a suction or lifting effect on a part or the whole of the roof. If the roof is flat or has a pitch of less than 45° the lifting effect extends over the whole roof. If the pitch exceeds 45° there is pressure on the windward and suction on the leeward side. Suction is especially powerful at the eaves of a nearly flat roof. In fact, over a building as a whole suction exceeds pressure; windows are more often blown out than in.

The most disturbed region is just to leeward of the ridge of the roof, where an eddy forms with a horizontal axis, the air moving in the direction of the wind above roof-level and against the wind lower down. But owing to the succession of gusts and lulls the velocity is always changing, and a succession of eddies breaks off and drifts away down-wind. These eddies cause alternating pressure and strong suction on the leeward side of the building, which is therefore most liable to damage.

The pressure exerted by the wind is proportional to the square of the speed; on a flat plate normal to the wind it is usually taken as $P=0{\cdot}003V^2$ where P is pressure in lbs. per square foot [1] and V is velocity in miles per hour. A. M. Thomas (1930) terms this the "velocity pressure." In the rear of the plate there is a suction effect which must be added to the pressure on the face. Consequently the total force acting on the plate exceeds the velocity pressure. On a rectangular flat plate of great length, such as a bridge girder, the total force is twice the velocity pressure. On a tall building directly facing the wind Thomas gives it as 1·6 times the velocity pressure, while on a square, flat plate such as a signboard the ratio falls to 1·1. Curved surfaces allow the air to flow past with less hindrance, consequently the pressure on them is less. For cylinders the effective area is not half the total surface, but only the area projected on a plane at right angles to the wind, or slightly less than one-third of the total surface, and the total force is only about 0·8 (chimneys, standpipes) or 0·7 (water tanks) times the velocity pressure on this effective area.

The failure of a gasometer in the tropics was found by C. A. Middleton (1937) to be due to suction causing the plates on the lee side to bulge outwards. The rivets were corroded much more on the lee side than to windward, and under the vibrations caused by continual variation of the suction with the passage of gusts and lulls they tore out. There was also suction on the dome of the gasometer. Middleton found both by calculation and experiment that the total suction on a cylinder in a high wind is much greater than the total pressure. Pressure is exerted on only one-sixth of the circumference directly facing the wind. The greatest suction is on either side, slightly to windward of the diameter normal to the wind.

[1] In Fig. 12 wind pressure is shown in millibars (mb.). One mb. is equivalent to slightly over 2 lb./sq. ft.

On surfaces inclined to the wind the pressure is naturally less than on similar surfaces directly facing the wind. Duchemin's formula, quoted by R. Fleming (1930), gives the factor by which the wind pressure on a surface at right angles to the wind must be multiplied as $2 \sin \theta/(1+\sin^2\theta)$, where $\theta$ is the angle between the surface of the building and the wind.

Building regulations in different countries differ as to the wind pressure to be allowed for in construction, but generally they require a safety limit of 30 lbs. per square foot, either over the whole structure or over the exposed parts. This is equivalent to a maximum gust velocity of 100 m.p.h., which is only exceeded, and that rarely, in the windiest parts of the British Isles (see below). It should be remarked that the maximum gusts are limited both in area and duration. Since the diameter of an eddy is about 50 to 100 feet, it follows that the maximum average pressure over any structure 100 feet or more long is appreciably less than the maximum at any one point. An estimate of 75 per cent. is quoted by Fleming as a safe figure. Also light structures such as radio towers, stack pipes, etc., respond quickly to wind pressure, and for these the maximum gust velocity over two seconds gives a good measure of the stresses. Heavier buildings, however, have a greater inertia, and for these the effective maximum wind speed to be considered is that over a period of minutes. This is only about 70 per cent. of the maximum gust velocity; the exact figure depends on the gustiness factor, being greatest when the latter is least.

Shelter by other buildings generally reduces the forces on the building sheltered, but may bring the latter entirely within the area of suction to leeward of the exposed building. Such cases are probably rare. Solid walls and fences have a similar effect. The best shelter is provided by a belt of trees or an open fence, which reduce the wind speed without creating dangerous eddies (see Chapter XII). Dangerous lifting forces on a roof may be minimised by the use of a longitudinal opening under the ridge of the roof, such as a louver, which often forms part of the system of ventilation.

One possibility of damage which is rarely considered is that the period of oscillation of an erection may coincide with the periodicity of gusts, so that resonance occurs. K. Döring (1925) gives the average period of oscillation of a chimney of reinforced

concrete 330 feet high as 2·4 seconds, but it is possible that with stronger winds the period increases. R. Fleming (1930) gives recordings indicating that buildings of light construction have an oscillation period of four seconds in gales, while those of heavier structure have a smaller oscillation of shorter period. The average interval between gusts being about seven seconds, it appears that danger from this cause will not often arise.

*Maximum gust velocities.*—The most violent known winds at the earth's surface occur in tornadoes. These are very impressive, estimates up to 400 m.p.h. having been quoted, but the strongest winds occur over a very small area, and the risk to any particular building is small. Even in the worst areas severe damage at any particular spot is only likely to occur once in 1,000 to 2,000 years. Tornadoes have therefore been left out of account here, since it is not economically practicable to construct buildings which will stand up to the centre of a tornado. They are discussed further in Chapter X.

*Dissipation of smoke.*—A study of the wind direction and structure is especially important where chimneys emitting smoke and noxious fumes are concerned. There are two aspects: the influence of topography on the local wind direction and the effect of turbulence in spreading and dissipating smoke and gases.

The local winds tend to follow the valleys, especially if these are narrow and steep-sided. Strong, gusty winds may sweep up and down such valleys. This fact must be considered in siting works which emit noxious fumes to avoid risk of damage and claims for compensation in other parts of the valley. A notable example occurred in the Columbia River valley, where fumes from smelting works at Trail in British Columbia travelled southwards into the State of Washington, causing damage to crops. The method recommended to mitigate the trouble in this case is described in Chapter IX.

Besides disturbances of the horizontal direction the topography may give the wind a prevailing upward or downward direction. The general air flow must follow the main features of the slope of the ground, but after blowing up a hillside the upward direction is continued by momentum for a short distance. After that the air descends again, and generally reaches the ground again at a distance of roughly a quarter to half a mile to leeward of the hill crest. In such a situation, with

a strong wind blowing over the crest, there is an almost permanent down draft. When the leeward slope of the hills is very steep (or behind a block of tall buildings) there is a powerful eddy, the wind actually blowing against the prevailing direction. Such down drafts may be very troublesome, interfering with combustion of furnaces or blowing the smoke down to the ground. Between this down draft and the crest there is a relatively calm region in which, however, the wind is very gusty.

Even in the absence of such down drafts, however, the gases from a chimney eventually reach the ground. It is only necessary to watch the plume of smoke from a chimney to see that it expands down wind, forming a cone with a horizontal axis. If the wind is very gusty the plume expands rapidly, and the cone has a broad apex. If the air flow is unusually smooth the plume expands slowly and the cone has a narrow apex. If the draught in the chimney is strong the gases are thrown some distance above the top before they begin to spread, but this effect is not appreciable unless the upward velocity of the issuing gases is twice the wind speed (slightly less than twice with strong winds). For the purposes of calculation it is more or less cancelled out by the down draft immediately behind the top of the chimney, so that the smoke trail may be assumed to start at chimney height. The rate of spreading is also affected by the diameter of the chimney, which governs the size of the trailing eddies with vertical axes formed behind the chimney; the turbulence is greater behind a broad chimney than behind a narrow one. The smoke from an *isolated* chimney will therefore reach the ground at a distance from the foot of the chimney which depends on the height and breadth of the chimney, the gustiness of the wind, and to a small extent the draught in the chimney. According to O. G. Sutton (1947) the maximum concentration at ground level from a chimney 160 feet high occurs at a distance of 720 yards in a very gusty wind, 1,300 yards under average conditions, and 3,400 yards when the air is nearly free from turbulence. These figures apply to normal horizontal flow of the air; if there is a down draft the maximum concentration of smoke is greater and occurs nearer the foot of the chimney.

If the chimney rises from the roof of a factory or other building, or if there are neighbouring buildings to windward, conditions are more complicated. Behind the building there is

a region of very turbulent air, which may extend to well above the level of the roof of the building. "Down wash" begins as soon as the smoke reaches this turbulent layer. R. H. Sherlock and E. A. Stalker (1940) carried out a series of experiments on models at Chicago from which they concluded that the down wash of stack gases occurs in two stages: (1) Down flow in eddies in the wake of the stack; (2) Dispersion of gases within the turbulent mass of air behind and above the buildings. In their experiment the building supporting the chimneys presented a blunt face to the prevailing wind, so that the turbulent layer extended nearly to the top of the chimneys. The height of the latter was 250 feet, and the model indicated that gases reached the ground at a distance of only 1,250 feet.

The nearer the top of the turbulent layer extends to the top of the chimney the greater is the danger of serious contamination of the air. If the effective height of the chimney can be raised above the top of the turbulent layer by a height greater than the diameter of the chimney there is little risk of serious contamination. Some of the gases will reach the ground at a greater distance by the ordinary operation of diffusion, but not in sufficient concentration to be harmful.

The remedy adopted by Sherlock and Stalker was to fit nozzles to the chimneys of greater height than the diameter of the latter. This had three results: it increased the effective height of the chimneys; it increased the upward velocity of the gases; and the eddies behind the nozzles being smaller than those behind the chimneys, the smoke was carried downwards less rapidly. These precautions were effective. This paper by Sherlock and Stalker is of great interest. One deduction is that in designing a factory, if smoke and noxious gases are likely to be troublesome, the face presented to the prevailing wind could with advantage be "streamlined" to some extent by setting back the upper stories and sloping the roof at a low angle.

Ordinarily smoke spreads both upwards and downwards, and half of it is dissipated into the air above and rendered harmless. In certain weather situations, however, known as *inversions*, there is a cold layer of air near the ground with warmer air above. The top of the cold layer acts like a lid; smoke accumulates below this "lid" and may form a dense pall—this is, in fact, the origin of town fogs. In such situations the emission of noxious gases may be very harmful, especially

in sheltered hollows and valleys. The possibilities in this direction are illustrated by the fog in the Meuse valley on 3rd to 5th December 1930 in the industrial area between Huy and Seraing, when sixty-four people (all old or in poor health) died, as well as a number of cattle.

## RAIN AND WIND

The penetration of rain into walls and through cracks, and direct mechanical damage by rain, are greatly increased when the rain is accompanied by a strong wind. The penetrating power of rain under these conditions is proportional to the intensity of the rain and the square of the wind velocity. The raindrops are broken up into a very fine mist, which is forced into the pores and cracks in the wall by the wind. This effect was discussed by W. Thelm (1933), who termed the occurrence "Schlagregen" (pelting rain, "shock rain"). The minimum conditions for damage by shock rain are a wind of 34 m.p.h. with a rainfall at the rate of 0·01 inch per hour, or about a quarter of an inch a day. Moderately severe shock rain occurs with a wind speed of 25 m.p.h. and a rainfall of 0·5 inch an hour, a wind of 30 m.p.h. and a rainfall of 0·36 inch an hour, or a wind of 35 m.p.h. and a rainfall of 0·25 inch an hour. If these conditions are maintained more or less continuously for two or three days severe damage is likely to occur. Unfortunately it is difficult to obtain the necessary data to find out how frequent and widespread shock rains are, but they are probably liable to occur once or twice in most winters in exposed places on the western coast of Great Britain and the north-west coast of Europe.

## CHAPTER III

## "TEMPERATE" CLIMATES OF THE OLD WORLD

THIS and the four following chapters give brief descriptions of the main climatic characteristics of the various land masses of the world. Their aim is not to set out strings of figures; such statistics can be obtained from the tables in the Appendix or, if required in greater detail, from the Meteorological Office, but to present a simple picture of the main peculiarities and the progress of the seasons. The land areas may be divided into *Polar*, *Temperate* and *Tropical*, conveniently separated by the Arctic and Antarctic Circles (66°30′ N. and S.) and the two Tropics (23°30′ N. and S.). In the polar regions the distinction between night and day almost vanishes except near the equinoxes; the year consists of a very long, hard winter and a very short summer. In the "temperate" regions the changes from day to night and winter to summer are both important, but the range of temperature between the averages of the warmest and coldest months exceeds the average daily range of temperature. In the interiors of the continents the annual range is very great, and "temperate" is a misnomer; it is to be read as a synonym for "middle latitude." Between the tropics the temperature contrast of the seasons becomes less important, and is exceeded by the contrast between day and night. "Night is the winter of the tropics," but the real seasons are defined by the variations of rainfall. It so happens that the area in which the daily range of temperature exceeds the annual range is almost exactly limited by the tropics, the only exceptions being India, where it is bounded by a line from Bombay to Madras, and the western coastal regions of South America, where it extends as far south as Santiago. As the temperate regions are by far the most important economically, these are discussed first.

In accordance with usual meteorological practice the seasons are defined as (in the northern hemisphere): winter, December to February; spring, March to May; summer, June to August; autumn, September to November. In the southern hemisphere these seasons are reversed, *i.e.* winter is June to August, etc.

In high latitudes and in the interior of the continents these "seasons" are little more than conventions; the year consists of winter and summer, with short transitional periods of about a month.

The weather of the temperate regions is governed by the constantly changing pressure distribution, in which the two main elements are the anticyclone and the barometric depression. An anticyclone is a region of high pressure, light winds and generally dry weather. In summer the sky is usually clear and the weather sunny and warm, giving ideal holiday weather, but in winter anticyclones in western Europe the sky is often covered by a uniform layer of grey cloud. In winter also anticyclones frequently bring fog, especially in towns where the light winds cannot dissipate the smoke. In the interior of Siberia there is an almost permanent large anticyclone in winter; in other parts of the temperate regions anticyclones appear from time to time in all seasons and drift slowly along irregular tracks.

The characteristic weather of most parts of the temperate regions results from the passage, in a general easterly direction, of a succession of barometric depressions. A depression is an area of low pressure round which (in the northern hemisphere) the winds blow in an anti-clockwise direction. In the southern hemisphere the direction of the winds is clockwise. In the northern hemisphere the winds in the foremost part of a depression advancing from west to east are southerly or south-easterly and generally mild and humid, with moderate, steady rain. In the rear of the depression the winds are northerly or north-westerly and bring a change to colder weather with showers and fine intervals. As the depression passes away to the east the showers become less frequent and a day or two of fine weather precedes the arrival of the next depression. There are usually one or two breaks in the smooth circulation of the air on the side of a depression nearest to the Equator; these are "fronts" where two masses of air of different origin come in contact. The "cold front," where the cold air in the rear of a depression replaces the warm air in the southern part, is usually marked by a rapid change of wind direction, with a squall and often a heavy shower. On the polar side of a depression the winds are easterly (north-east in the northern hemisphere, south-east in the southern). These winds are cold and often

bring heavy snow in winter. They are less liable to be interrupted by squalls than the winds on the equatorial side of the centre, and the snow or rain is often very persistent.

Depressions vary greatly in size and intensity. The average diameter is 1,000 to 1,500 miles, but a deep winter depression may have a diameter up to 3,000 miles and bring heavy rain and persistent gales along the whole Atlantic coast of Europe. The wind may reach speeds of 60 or 70 m.p.h. averaged over an hour or more, and much higher speeds in gusts. Similar conditions are found in the Aleutians and on the western coast of Canada, Washington and Oregon, on the coast of New England, Newfoundland and the maritime provinces of Canada. In the interior of the continents the winds are less strong. In summer depressions are smaller and generally less intense, but severe storms sometimes occur and bring gales over limited areas.

It is the frequent but irregular passage of depressions, and the intervening fine periods of varying lengths, the fresh but rarely destructive winds, the alternation of rain and sun, and the constant changes of temperature which give the climates of the temperate regions their stimulating character, especially in the coastal regions. The weather is often moderately uncomfortable, but never so extreme as to numb the faculties and cause a feeling of hopelessness. The peoples of these regions are "conditioned" to change, and hence more alert and less liable to get into a rut than those of less variable climates. That is probably the main reason why the "cyclonic temperate" regions (see fig. 1) are among the main centres of progress.

BRITISH ISLES (Appendix I—Birmingham, Cardiff, Dover, Falmouth, London, Manchester, Portsmouth, Tynemouth, Yarmouth; Aberdeen, Edinburgh, Lerwick, Stornoway; Belfast, Cork, Dublin).

The climate of the British Isles is both equable and changeable. Extremes of heat and cold, or of drought and heavy rain are rare, but the weather seldom remains the same for longer than ten days or so at a time. The mean annual temperature below a height of about 500 feet is everywhere between 45° and 52° F. On the west coasts and islands the coldest month is February, elsewhere January; similarly, the warmest month in the west is August and in the east July. The difference between the warmest and coldest months nowhere exceeds 25° F., and on the west coasts and islands is only 15°. As is usual in oceanic

climates, winter tends to be prolonged into spring, which is a treacherous, uncertain season, and summer into autumn. Extreme temperatures are rare; in London in over a hundred years the thermometer has only once touched 100° F. and has never fallen below 4° F.; in an average year the range is from 85°–19°. Lower temperatures are found in the northern Midlands and southern Scotland, but in the more populous parts of the country it is not necessary to reckon with a temperature lower than 5° F. once in ten years.

Really severe winters are rare; in the past seventy years the outstanding ones have been: 1879–80, 1890–91, 1894–5, 1939–40 and 1946–47. Of these 1890–91 and 1946–47 were the worst, of about equal severity.

December 1879 was the coldest month of the century in France and central Europe, and the cold persisted into January; the Dutch waterways were frozen for nearly two months, and in Paris fifty people died of cold. In Britain the winter was not so severe, but deaths from cold were reported and evergreens were killed. On 4th December a temperature of −23° F. was recorded at Blackadder, in Berwickshire, but this is not officially recognised, as the thermometer was uncertified and not conventionally exposed.

The winter of 1890–91 was remarkable for its long duration, from 25th November to 22nd January, rather than for the intensity of the frost. During this period the average temperature was below 32° F. over nearly the whole of England and Wales, and below 30° in East Anglia and the south-east Midlands. Skating in Regent's Park occurred on forty-three days, the thickness of the ice exceeding 9 inches, but the frost penetrated the ground to a depth of barely a foot.

The frost of 1894–95 lasted from 30th December to 5th March with one break; the coldest day was 11th February when −17° F. was recorded at Braemar, the lowest in Britain which is officially recognised. From 9th to 17th February the whole of the Thames was more or less blocked by ice-floes, some of them 6–7 feet thick.

The winter of 1939–40 was not so intense as that of 1894–95, but was longer and snowier. It was notable for the glazed frost at the end of January (see p. 47).

The winter of 1946–47 ranks with that of 1890–91 as probably the worst in Britain since 1789. Not only was it very long, but

there were heavy and repeated falls of snow, a long succession of sunless days and persistent biting east winds; the greater part of Great Britain and Northern Ireland was continuously snow-covered from 27th January to 13th March. Level depths exceeded 2 feet and there was much drifting. The dislocation of road and rail traffic was unprecedented.

The *rainfall* of Britain is generally moderate and well distributed through the year. On low ground it increases from about 20–25 inches a year in south-east England to 40–50 inches in the west and north-west. The wettest places are near the summits of the mountains; in Wales, Cumberland and western Scotland the rainfall approaches 200 inches. These rainy hilly regions are of value as gathering grounds for the water supply of large towns and for hydro-electric power.

The rainfall is generally reliable, which is fortunate for the dense population of Britain with their large water requirements. Droughts lasting for more than six months are rare. The outstanding droughts since 1864 are summarised below. Fuller accounts of those from 1864–1921 are given by C. E. P. Brooks and J. Glasspoole (1922).

TABLE 14.—Droughts in Britain.

| Year | Period | Months | Percentage of Average Rainfall | |
|---|---|---|---|---|
| | | | England and Wales | Scotland |
| 1864 | April–August | 5 | 61 | 73 |
| 1868 | May–July | 3 | 38 | 67 |
| 1879–80 | October–January | 4 | 36 | 58 |
| 1887 | February–July | 6 | 57 | 73 |
| | February–October | 9 | 68 | 77 |
| 1893 | March–June | 4 | 43 | 72 |
| 1895 | February–June | 5 | 62 | 72 |
| 1896 | January–May | 5 | 60 | 79 |
| 1921 | February–July | 6 | 49 | 84 |
| | February–October | 9 | 58 | 89 |
| 1929 | January–April | 4 | 47 | 51 |
| 1938 | February–April | 3 | 31 | 70 |
| 1947 | August–December | 5 | 57 | 78 |

Droughts are generally most severe in south-east England, where the rainfall is not only lower than in the rest of the country, but also more variable from year to year.

Evaporation is greatest in summer, when it generally exceeds the rainfall in the drier parts of the country, and in an average year most of the rain which falls in summer is evaporated without penetrating the sub-soil. The underground water, which maintains the springs and rivers in dry periods, is mostly the accumulation of the winter rains, so that a winter drought, though less spectacular than a hot, dry summer, has a greater effect on our reserves of water.

Although the winter weather of the British Isles can be described as stormy, widespread damage by wind is rare, and is chiefly limited to the blowing down of trees and to minor damage to buildings. There is some risk to trains travelling along exposed sections of line (the Tay Bridge disaster of 28th December 1879 was caused by a gale), and at Quilty in west Ireland an anemometer was installed which rings a bell when the wind reaches 65 m.p.h., as a warning to weight the trucks of trains, and again at 85 m.p.h., when traffic is stopped along an exposed section of the railway. The most severe storms generally bring heavy rain and may result in minor flooding. Serious floods may be due to a variety of causes: intense local thunderstorm rains, long-sustained heavy rains generally accompanying a slow-moving barometric depression, or a succession of storms with mild air and heavy rain following a period of deep snow cover and frozen ground. In tidal rivers the effects of floods are accentuated when the peak coincides with a period of unusually high tide caused by the piling up of river water by storm winds. The flood in the Thames estuary on 6th–7th January 1928, when fourteen people were drowned by the flooding of basements in London, was due almost entirely to the piling up of the tidal water by a storm. For descriptions of the most severe floods, see C. E. P. Brooks and J. Glasspoole (1928).

The storms which cause the greatest inconvenience in the British Isles are those in which strong winds are accompanied by heavy snow. These are popularly termed "blizzards," and though they do not bring the very low temperatures and dry, powdery snow of the true American blizzards, they are sometimes not dissimilar. In the past seventy years we may recall three such storms in southern England:—

18*th*–20*th January* 1881.—This affected the greater part of England, and was most severe from Somerset to the Isle of

Wight; snow in the streets of London interfered with traffic for a fortnight.

*9th–13th March* 1891, which was worst in Devon and Cornwall. Several trains were buried for days on Dartmoor, and passengers narrowly escaped starvation.

*26th December* 1927.—This brought more than a foot of undrifted snow on high ground, and the deep drifts piled up by the gale blocked some roads for a week. The snow was soft and clingy, and broke down many telephone wires.

The worst snowstorms of recent years in northern England were those of the end of February and beginning of March 1886 and 4th–5th March 1947. A detailed account, year by year, of snowfalls in the British Isles from 1876 to 1925 is given by L. C. W. Bonacina (1927).

In spite of these occasional *contretemps* the climate of Britain and especially of south-east England is, on the whole, ideal for most forms of human activity. The average summer temperature is very near the optimum, and the winters are cold enough to be bracing, but not too cold for simple heating methods to be effective without elaborate air conditioning. The humidity is moderate, without either excessive dryness to cause nervous irritation and dust nuisance or long periods of enervating damp heat. The rainfall is adequate without being excessive. There is generally enough wind to clean the air and ventilate buildings; the dirty fogs of large towns are only isolated nuisances. Above all the weather is not monotonous. Northern England and Scotland are almost equally favourable, but the winters of the central and eastern districts are harsher and, especially in the west, the periods of favourable anticyclonic weather are fewer and shorter. The climate of Ireland is even more equable—in fact too equable, the winters being too mild to provide the tonic effect of this season in Britain.

Although the succession of wet and dry, stormy and fine periods is at first sight chaotic, careful study has revealed a pattern. Around certain dates definite types of weather tend to recur in from half to almost all the years. An account of these "recurrences" was given by C. E. P. Brooks (1946*a*). The principal tendencies are as follows:—

(1) October to early February, stormy periods with minor anticyclonic interludes.

(2) February to May, cold waves associated with north-easterly winds.

(3) The summer period of alternating cool fresh north-westerly and warm, sultry south-westerly winds.

(4) September and early October, spells of anticyclonic conditions and late "summers."

The principal stages in the seasonal succession, with their average and peak dates of occurrence and the number of times they occurred in the fifty-two years 1889–1940 are as follows:—

| Type | Average Dates of | | | Frequency in 52 years |
|---|---|---|---|---|
| | Beginning | Ending | Peak | |
| Early January, stormy | Jan. 5 | Jan. 17 | Jan. 8 | 45 |
| Mid-January, anticyclonic | Jan. 18 | Jan. 24 | Jan. 20–21 | 45 |
| Late January, stormy | Jan. 24 | Feb. 1 | Jan. 31 | 44 |
| Early February, anticyclonic | Feb. 8 | Feb. 16 | Feb. 13 | 29 |
| Late February, cold spell | Feb. 21 | Feb. 25 | Feb. 22 | 22 |
| Late February and early March, stormy | Feb. 26 | Mar. 9 | Mar. 1 | 46 |
| Mid-March, anticyclonic | Mar. 12 | Mar. 19 | Mar. 13–14 | 27 |
| Late March, stormy | Mar. 24 | Mar. 31 | Mar. 28 | 35 |
| Mid-April, stormy | April 10 | April 15 | April 14 | 37 |
| Late April, unsettled | April 23 | April 26 | April 25 | 27 |
| June, summer monsoon | June 1 | June 21 | — | (40) |
| July, warm period | July 10 | July 24 | — | — |
| Late August, stormy | Aug. 20 | Aug. 30 | Aug. 28 | 35 |
| Early September, anticyclonic | Sept. 1 | Sept. 17 | Sept. 10 | 43 |
| Mid-September, stormy | Sept. 17 | Sept. 24 | Sept. 20 | 31 |
| Early October, stormy | Oct. 5 | Oct. 12 | Oct. 8–9 | 35 |
| Mid-October, anticyclonic | Oct. 16 | Oct. 20 | Oct. 19 | 35 |
| Late October and early November, stormy | Oct. 24 | Nov. 13 | Oct. 29, Nov. 9, 12 | 52 |
| Mid-November, anticyclonic | Nov. 15 | Nov. 21 | Nov. 18, 20 | 34 |
| Late November and early December, stormy | Nov. 24 | Dec. 14 | Nov. 25, Dec. 9 | 51 |
| Pre-Christmas, anticyclonic | Dec. 18 | Dec. 24 | Dec. 19–21 | 29 |
| Post-Christmas, stormy | Dec. 25 | Jan. 1 | Dec. 28 | 43 |

These characteristic spells of weather do not occur every year, and when they do come the dates are not always exact—there may be a range of a week on either side. They are therefore in no sense *forecasts* of the weather to be expected in any

particular year, but the table is a useful guide in planning activities when the date has to be decided more than five days or so ahead. Really "long range" forecasts, weeks or months ahead, are not yet practicable in temperate regions. In particular, "weather cycles" such as the "sunspot cycle" of eleven years and the "Brückner cycle" of thirty-five years are quite unreliable in spite of the publicity which they have received. This may be illustrated by the fact that the year 1921, about the driest on record in England, came near the middle of the wet half of a Brückner cycle. Official forecasts are usually reliable for twenty-four hours, and in general terms for forty-eight hours ahead, and are occasionally possible for five days or even a week, but anything beyond this is at present little more than guesswork. For a description of the organisation of weather forecasts in Britain, see E. G. Bilham (1947). For a detailed study of the climate of the British Isles, with numerous maps and tables, see E. G. Bilham (1938).

NORTH-WEST AND CENTRAL EUROPE (Appendix I—*Austria*, Innsbruck, Vienna; *Belgium*, Brussels; *Czechoslovakia*, Brünn, Karlsbad, Prague; *Denmark*, Copenhagen; *Faeroes*, Thorshavn; *France*, Bordeaux, Cherbourg, Paris, Strasbourg; *Germany*, Aachen, Berlin, Breslau, Frankfurt-am-Main, Hamburg, Leipzig, Munich, Stuttgart; *Holland*, Flushing, Utrecht; *Hungary*, Budapest; *Norway*, Bergen, Oslo, Tromso; *Sweden*, Haparanda, Stockholm; *Switzerland*, Berne, Geneva, Zurich).

Owing to the absence of north-south mountain ranges the climate of the whole North European plain between the Baltic and the Alps changes only gradually from west to east over the whole stretch from Britain to the Urals. The winters grow more severe as we pass eastwards (a very severe winter in London would be regarded as normal in Berlin), the snow cover is more regular and persistent, the rise of temperature in spring is more rapid, the summers are somewhat warmer, rainier and more thundery, and autumn to some extent loses its pleasant character as an extension of summer. The difference is most marked in winter; summer in, for example, Warsaw is not greatly different from summer in London. The change is most rapid within a few miles of the coast; Paris, for example, in spite of its lower latitude, is on the average slightly colder in January than is London, and the extremes of cold are far more intense. This is because the moderating influence of the North

Sea on the cold north-east winds is absent. The lowest temperatures on record are (in ° F.): Flushing, +3; Utrecht, −5; Berlin, −15; Warsaw, −22; Moscow, −31; Kasan, −34; Sverdlovsk, −43. The spells of mild, damp weather associated with stormy conditions in winter extend far into Europe, but become shorter and less pronounced as one goes eastwards; at the same time the frequency of gales decreases.

In spring north-easterly winds reach their greatest frequency and cause spells of cold weather, which often damage crops. These spells are popularly associated with the famous "Ice Saints" of 11th–13th May, but actually such cold spells are liable to occur at any time during April and May. Apart from these cold spells spring is a pleasant, calm season.

About the end of May there is often a sudden change in the prevailing type of weather. This brings in the "European Monsoon" (see p. 102) and takes the form of a rapid increase in the frequency and strength of westerly and north-westerly winds, especially on the Baltic coast of Germany. Fresh, breezy, showery weather sets in and usually lasts for about three weeks. By the end of June summer conditions of fine hot spells alternating with thundery rains have generally set in. Towards the end of September, in most years, especially in central and eastern Germany and western Russia, there is a period of fine anticyclonic weather known as the "Old Wives' Summer"; it resembles the "Indian Summer" of North America. The average duration is from 24th September to 4th October; it occurred in thirty-three of the fifty-two years 1889–1940. Similar, but shorter, more uncertain and progressively colder "late summers" may recur during October and November. Accounts of the European Monsoon and Old Wives' Summer are given by C. E. P. Brooks (1946a).

In Scandinavia the eastward change of climate is much more rapid owing to the mountainous backbone of the peninsula, which shuts out the winds from the Atlantic. The climate of Norway is mild, rainy and stormy, with heavy snowfalls at high levels; it resembles that of western Scotland, but is about 6° F. colder in winter at the same level. The climate of Sweden is much quieter and colder in winter and warmer in summer; it belongs rather to the east European type. The Gulf of Bothnia is largely frozen in winter (see p. 50) and this adds to the

severity of the season. It is only in autumn that Sweden and western Finland take on the west European type of climate.

EASTERN EUROPE AND SIBERIA (Appendix I—*Bulgaria*, Sofia; *Estonia*, Tallin, Tartu; *Finland*, Helsinki, Oulu; *Latvia*, Riga; *Lithuania*, Kaunas; *Poland*, Danzig, Lwow, Warsaw; *Roumania*, Bucharest; *U.S.S.R.* (Europe), Archangel, Astrakhan, Leningrad, Lenkoran, Moscow, Odessa, Tiflis; (Asia), Barnaoul, Irkutsk, Markovo, Okhotsk, Sverdlovsk, Tashkent, Verkhoiansk, Vladivostok).

The North European plain broadens eastwards and, apart from the Urals, which are not high enough to act as a real climatic divide, forms a monotonous plain extending from the southern mountains to the Arctic Ocean. In this great region all life is completely dominated by climate. There are three great zones extending from west to east. The mountains which form the southern boundary are bordered on the north by extensive steppes, becoming true desert in the Trans-Caspian region. Here winters are very cold, summers intensely hot. Where water supply is sufficient, or irrigation is practicable, this is rich agricultural country, but large areas of Asia support only a scattered nomad population with local aggregates in mining areas. Next comes a belt of forest from about latitude 55° N. to the Arctic Circle. This is the most important part of the region economically, and the Trans-Siberian railway runs through it. The forests, in fact, supply most of the fuel for the locomotives. Finally comes the tundra, extending to the Arctic coast, a region of long, cold winters and short, dull summers, of little value and occupied only in small scattered settlements. The industries are mining and hunting or trapping. The Arctic climate is discussed on p. 165.

The winters of Russia and Siberia are long and intensely cold, increasing in severity from the western borders to Verkhoyansk ($67\frac{1}{2}$° N., $133\frac{1}{2}$° E.). Continuing the series on p. 104, but a little farther north, we have as the lowest temperatures on record (° F.): Leningrad, −36; Archangel, −49; Barnaoul, −55; Eneseisk, −73; Verkhoyansk, −94; Okhotsk, −50. These figures sound impressive, but the cold is not as bad as it sounds. The breath freezes and falls in a white powder, but the air is dry and bracing, and during extreme cold there is never any wind. The hard, dry snow surface forms excellent going,

and winter is the favourite season for travel. One can move about freely on the level in calm air with a temperature of −60° F. (though the ascent of even a small hill renders breathing difficult), but a snowstorm at +5° F. is almost unbearable. The great drawbacks of the winter climate are the necessity for continuously wearing heavy furs, the impossibility of maintaining personal cleanliness, and the deadening monotony. Owing to the dryness of the air the winter climate is very healthy, lung complaints and all epidemics except smallpox being unknown. In spite of the apparently bracing quality of the weather, however, the cold saps the energy of the inhabitants. Western Russia and the bordering countries are fairly bracing and encourage mental and physical activity, but the climate becomes less favourable to the north, east and south. The difference is, however, one of degree rather than of kind, and the U.S.S.R. do not enjoy the variety of climate and resources which characterise the United States or the British Commonwealth.

Although there are numerous light falls of snow the total amount is small, equivalent to less than a foot of undrifted snow. But the open country is swept by intense blizzards known as *buran* in south Russia and central Siberia and *poorga* in northern Siberia. These sweep up the dry snow in blinding sheets, and are very dangerous to travellers. They form drifts with intervening patches of bare soil through which the cold penetrates into the ground.

The worst season comes at the end of winter—to call it "spring" would be a misnomer. Between March in the southwest and May in the north the ice breaks up in the rivers and drifts downstream, forming great ice-jams. Since the main rivers flow northward the ice breaks up first in the upper reaches and large areas in the valleys are flooded, while the melting of the snow and surface thawing cover the ground with sticky mud. At this season the country is almost impassable. Summer, though short, is hot and sunny (except near the Arctic coast, which has much fog at this season) and has a moderate rainfall. Since there is no danger of frost, vegetation flourishes and crops can be grown surprisingly far north. In late summer the climate of European Russia and western Siberia is pleasant, but eastern Siberia is damp and foggy, and this is the least healthy season. At this season the rivers are low and navigation

is difficult. Winter begins rather suddenly in October; there is no "autumn."

The east coast of Siberia has an unpleasant climate. Winter is not so cold as in the interior, but there are persistent strong, dry north-west winds, especially in the Amur valley. Summer is damp, cloudy and cool, with south-east winds which bring much fog and drizzle in the north and heavy rain in the Amur valley; the occasional west winds are accompanied by clear skies and swarms of mosquitoes.

Northern Sakhalin has a most peculiar climate. Owing to the icy seas the coast is very cold, almost Arctic, and the damp, undrained valleys are occupied by peat-bogs and reindeer, yet at a moderate height in the interior the climate is almost subtropical.

## THE ALPS

The mountainous region of the Alps and to a lesser extent the Carpathians and other ranges of central Europe are of interest chiefly for holiday resorts, winter sports, and sanatoria. They may be divided into mountain and valley climates. The effects peculiar to high altitudes are discussed in Chapter VII. Of the valleys all that can be said is that they are exceedingly diverse; every valley has its own climate, and where a valley does not run north and south there is a further sharp distinction between the two sides of the same valley. Northward-facing slopes (ubacs) are especially unfavourable owing to the lack of sunshine, and most settlements are situated on the southward-facing slopes (adrets). The most favoured spots are the "climatic oases," situated in wide valleys opening to the south and sheltered to the north and east by encircling mountains. Valleys opening to the north and east are intensely cold, and may be termed "little Siberias."

A remarkable feature of the climate of high levels in the Alps is the large amount of sunshine in winter. At that season there is less cloud than in summer, and the higher resorts are generally above the level of the tops of the clouds, so that in spite of the shorter days there is almost as much sunshine as in summer. At Säntis the average duration (hours per day) is: December, 4·3; April, 5·7; June, 4·8; August, 5·7. Owing to the thin atmosphere the sun's rays are but little weakened, and are reflected from the snow surface, so that in spite of the low

air temperature the body feels warm. The high-level resorts are especially rich in ultra-violet radiation, to which they owe much of their health-giving qualities.

A characteristic of the Alps is the Föhn, a warm, dry wind which blows down the northern sides of the mountains whenever a southerly wind crosses the summits. It is best seen in the deep winding valleys which penetrate into the mountains; here it may blow on forty or fifty days a year, chiefly in autumn and winter. Because of the Föhn the winter temperature of Altdorf averages 3° F. higher than that of Zurich. The temperature may rise as much as 40° F. in a day. Snow melts rapidly and the thaw water causes sudden floods. The air is very dry and there is risk of fires; in some villages smoking in the streets is forbidden during Föhn (W. G. Kendrew, 1930). Just before the onset there are rapid small oscillations of pressure which are said to cause nerve troubles.

The rainfall of the Alpine districts is plentiful, and the water supply is maintained in summer by the melting of the glaciers and lower snowfields. This combined with the rugged topography and numerous mountain lakes has favoured the development of hydro-electricity, especially in Switzerland, where it is used to provide power not only for railways, street cars and factories, but in all the farms and in the home industries for which the country is famous.

THE MEDITERRANEAN (Appendix I—*Albania*, Durazzo; *Cyprus*, Nicosia; *France*, Lyons, Marseilles, Nice, Ajaccio (Corsica); *Gibraltar*; *Greece*, Athens, Salonica, Candia (Crete); *Italy*, Genoa, Milan, Palermo, Rome, Venice; *Malta*; *Portugal*, Lisbon; *Spain*, Barcelona, Cadiz, Madrid, Palma; *Turkey*, Ankara, Istanbul, Smyrna; *Yugoslavia*, Belgrade, Zagreb; *Palestine*, Haifa, Jersualem; *Algeria*, Algiers, Oran; *Egypt*, Alexandria, Cairo; *Libya*, Benghazi, Tripoli; *Morocco*, Cape Spartel; *Tunisia*, Tunis).

The region lying between the mountain ranges of the Pyrenees, Alps and Caucasus in the north, and the deserts of the Sahara and Arabia in the south, has mild, more or less rainy winters and long hot dry summers, a climate so characteristic as to be known as the "Mediterranean" type. Spain and Asia Minor form transition regions to the continental type; the large land area and rugged topography make the climate

of the interior very rigorous in winter and intensely hot in summer, and northern Spain has been described as "nine months winter and three months hell"; spring is the most pleasant season, but even that is subject to violent changes of temperature. The Mediterranean climate is seen at its best in southern France, northern and central Italy and the coast of Greece, where there is a fair amount of rain in all months and summer in not unpleasant, but the north coast of Africa, the lowlands of Asia Minor and Syria are nearly or quite rainless and very dusty from June to August or September. Over the whole region the rainfall is very variable, long droughts alternating with short periods of heavy rainfall. On the European coast heavy thundery rains amounting to 6 or 8 inches in a day are not uncommon, especially in spring, but on the African side heavy falls are much less frequent. Over the whole region there is little of the prolonged dull skies and steady rain of north-west Europe; the clouds build up rapidly in a blue sky and almost directly the rain stops the sun is shining again. On the Egyptian coast the rainfall is very scanty, averaging only 4 inches at Alexandria, 3 inches at Port Said and little more than an inch at Cairo; the prosperity of Egypt is entirely due to the annual Nile flood. Irrigation is also necessary in parts of south-east Europe and south-west Asia, but in some of the backward countries it is rather crude.

The Mediterranean is famous for its sunshine. Very few places outside the mountain districts have less than 2,000 hours a year, and the Egyptian coast exceeds 3,000, an average of $8\frac{1}{2}$ hours a day. Even in December and January most parts receive more than 3 hours a day, the exceptions being the Balkan highlands and northern Italy; the latter is very misty. Spain and Portugal average $4\frac{1}{2}$ hours. In July and August the sun shines for 10 or more hours a day over the whole area.

The winds are not so strong as in north-west Europe, but there are some important local winds. In the south of France occurs the well-known *mistral*, a violent north or north-west wind which is especially developed in the lower Rhone valley, where it is regarded with terror. It is very cold and dry, injuring delicate plants; gardens must be protected by high walls or thick cypress hedges. At Marseilles its average frequency is 110 days a year, mostly in winter and spring, and it may continue

for a week, increasing in force in the afternoon and falling off again in the evening. It induces the irritable depression known as cafard. Very similar is the *bora* of the Adriatic, the Balkan Peninsula and the Black Sea near Novorossiisk. This is a dry, cold wind blowing in violent gusts from the north-east. It is most frequent in winter, when it may blow for weeks. In Gibraltar, a cool damp east wind, the *levanter*, is feared because it brings a feeling of lassitude.

Opposite in character is the *scirocco*, an unusually warm southerly wind which prevails chiefly in Italy. As a rule it is damp and oppressive, bringing cloud and rain, and this is the characteristic wind of winter; another form is a very hot, dry and dusty wind which occurs in Sicily and southern Italy. The temperature may rise to 95° F. at any hour, and the dust, which originates in the Sahara, is so thick as to colour the sky yellow and hide the sun. This wind is extremely drying and destructive to vegetation. There is no rain, or at most a few drops. This form of scirocco may occur in any month but is most frequent in spring. A similar wind, the *leveche*, occurs in Spain; in Madeira it is known as *leste*. The *khamsin* of Egypt is of the same character, remarkable for its extreme dryness; at Cairo humidity has been known to fall to 2 per cent. and temperature to rise to 109° F. The khamsin is accompanied by sudden sandstorms in which the wind reaches gusts of 35 m.p.h. It is most frequent in March, April, and May. These hot, dust-bearing winds reach their greatest intensity in the dreaded *simoom* of the deserts of Algeria, Syria and Arabia (see p. 161). The coasts and islands of the western Mediterranean enjoy very favourable winters and are the region of winter health resorts *par excellence*. Spring is treacherous on the Mediterranean coasts of Europe and Asia, with sudden falls of temperature, especially in Palestine, which bring a feeling of greater cold than is shown by the thermometer.

The long hot summer, which is prolonged into autumn, is unfavourable to exertion, and the Mediterranean is the home of the "siesta." Moreover, except in Spain and Portugal, Morocco and the western Riviera, there is malaria about. For these reasons the Mediterranean countries are not so advanced industrially as those farther north, where full activity can continue unchecked all day throughout the summer.

IRAQ (MESOPOTAMIA) AND IRAN (PERSIA) (Appendix I—*Iraq*, Baghdad, Basra, Mosul; *Iran*, Bushire, Teheran).

The Mediterranean type of climate, with rainy winters and hot, dry summers, extends eastwards across south-west Asia, becoming more extreme. The winter rainfall is not heavy but is generally sufficient for pasture, and where irrigation is practicable, as on the banks of the Tigris and Euphrates, rich crops can be grown, especially dates. The rivers are highest in spring, when the mountain snows are melting, and lowest in autumn, after the rainless summer. In the lowlands of the interior winter is a pleasant season, and the great heat of summer is made bearable by the dryness of the air. The Persian Gulf on the other hand is notorious for its damp sticky heat. The humidity at night is so great that everything becomes sodden, clothes, boots, books, go mouldy, and it is often noon before the sun dries out the moisture. Sleep is hard to achieve, and there is risk of heat stroke.

The interior of Iran forms a high sub-tropical plateau, arid, intensely cold in winter, when the lakes and rivers freeze, no spring or autumn, and extremely hot and dry in summer, but with relatively cool and refreshing nights. At heights of 5,000 to 6,000 feet the summers do not even feel hot, but a short exposure of the bare head to the sun will cause headache and probably sunstroke. Journeys are generally made by night or early morning.

The Iranian province of Seistan is renowned for its winds. In winter true "blizzards" occur, one of which is said to have given a maximum wind speed of 120 m.p.h. In May and early June there is a respite, but then the "wind of 120 days" sets in, blowing from north-west with a speed which sometimes reaches 70 m.p.h., and carrying huge quantities of dust. But at least the strong wind blows away the flies, which by this time of year are getting troublesome, and most of their attendant diseases. The wind also drives numerous windmills which raise the underground water into irrigation channels.

AUSTRALIA AND NEW ZEALAND (Appendix I—*Australia*, Canberra, Bourke, Sydney, Alice Springs, Brisbane, Normanton, Adelaide, Melbourne, Broome, Perth, Hobart; *New Zealand*, Auckland, Christchurch, Dunedin, Wellington).

These two dominions are conveniently included here because, although Australia extends far into low latitudes, the most

populous parts have a characteristic temperate climate. The northern coast of Australia, typified by Darwin, has a tropical monsoon climate, which extends down the east coast of Queensland as far as Brisbane; this is described on p. 144. The basin-like interior is hot and dry and largely desert; the annual rainfall of Alice Springs for example is only 11 inches and is very irregular. The south coast from Perth to Adelaide has a "Mediterranean" type with hot, dry summers and equable rainy winters. In the interior flies are a nuisance even in winter and almost unbearable in summer. New South Wales and Victoria are definitely warm temperate; Sydney has a fairly heavy rainfall throughout the year, much of the summer fall coming in rather violent thunderstorms. There is a good deal of hail, and a summer seldom passes without a report from somewhere in the interior of hailstones as big as hens' eggs. The south and south-east coasts suffer from hot winds (brick-fielders) from the interior three or four times each summer; the dry heat injures vegetation. Sydney is protected from these by the Blue Mountains, but Melbourne has experienced maxima of over 100° F. on six successive days. The climate of Tasmania closely resembles that of the maritime parts of southern England, allowing for the inversion of seasons; Victoria is similar but a good deal warmer, and frost is almost unknown. Tasmania and Victoria have the most stimulating climate of Australia, but probably do not equal England in this respect.

Australia is moderately stormy. Tropical cyclones known as "willy-willies" occur on the north-west coast between late November and late April, and have produced gust velocities exceeding 100 miles an hour. In the east also tropical cyclones approach the coast of Queensland in late summer and autumn, but their tracks are mostly offshore. When they strike the land they do a great deal of damage, both by the winds and by the floods which follow the very heavy rainfall. At Crohamhurst 35 inches has been recorded in a day and 77 inches in four days. Tornadoes of the American type, but less severe, are occasionally met with in the north and east; for example, a tornado-like thunderstorm visited Sydney in January 1889. The best known storms are the "southerly bursters" which occur mainly in late spring and summer, and reach their greatest intensity on the coast of New South Wales. These are violent squalls in which the wind changes suddenly from north to south, with a great

drop of temperature. Storms in Victoria may bring rainfalls of 10 inches or more in a day in the mountains, and cause severe floods in the Darling River.

Australia's chief trouble, however, is shortage and unreliability of rainfall, much of the centre and south having an annual total of less than 10 inches, while evaporation is very great, exceeding 100 inches a year in the dry regions. Most of the rain

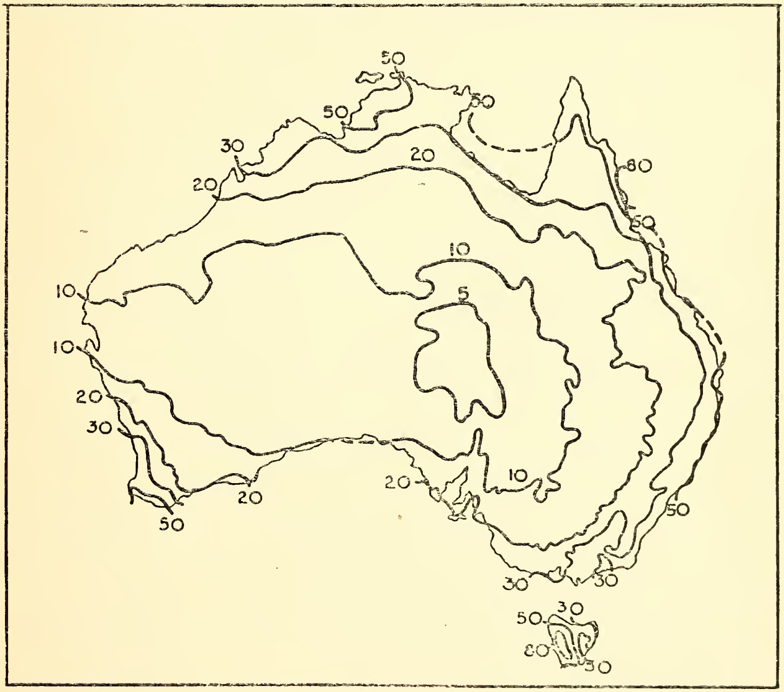


Fig. 13.—Mean Annual Rainfall of Australia, inches.

here falls in short heavy showers which do little good. The smaller rivers dry up in the dry seasons and the lakes are reduced to mud holes or salt pans, so that there is little chance of irrigation except where artesian wells yield a good supply. The artesian wells of eastern Australia are famous, and have done a great deal to aid the development of the drier regions. The supply of underground water is limited however, and is beginning to show signs of exhaustion. The total yield now is smaller, in spite of the greater number of wells, than when the water-bearing layer was first tapped. In the marginal areas

agriculture is very precarious. The following table shows the annual variation of rainfall at selected places (inches):

| | Lat. S. | Jan. | Feb. | Mar. | April | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Queensland* | | | | | | | | | | | | | |
| Thursday Is. | 10 34 | 17·4 | 16·2 | 13·8 | 8·0 | 1·7 | 0·5 | 0·4 | 0·2 | 0·1 | 0·3 | 1·4 | 7·4 |
| Cooktown | 15 28 | 14·4 | 13·8 | 15·3 | 8·9 | 2·9 | 2·0 | 1·0 | 1·2 | 0·6 | 1·0 | 2·5 | 6·6 |
| Rockhampton | 23 24 | 7·7 | 7·7 | 4·3 | 2·5 | 1·6 | 2·6 | 1·8 | 0·8 | 1·3 | 1·8 | 2·4 | 4·8 |
| *New South Wales* | | | | | | | | | | | | | |
| Sydney | 33 52 | 3·6 | 4·2 | 4·9 | 5·5 | 5·0 | 4·8 | 4·8 | 2·9 | 2·9 | 2·8 | 2·8 | 3·0 |
| *Canberra* | 35 20 | 1·8 | 1·7 | 2·2 | 1·6 | 2·0 | 2·1 | 1·9 | 2·1 | 1·7 | 2·1 | 2·0 | 2·1 |
| *Victoria* | | | | | | | | | | | | | |
| Melbourne | 37 49 | 1·9 | 1·7 | 2·2 | 2·3 | 2·1 | 2·1 | 1·9 | 1·9 | 2·3 | 2·7 | 2·2 | 2·3 |
| *Tasmania* | | | | | | | | | | | | | |
| Hobart | 42 53 | 1·9 | 1·5 | 1·7 | 1·8 | 1·9 | 2·2 | 2·2 | 1·9 | 2·1 | 2·2 | 2·5 | 2·0 |
| *Northern Territory* | | | | | | | | | | | | | |
| Darwin | 12 28 | 15·8 | 12·9 | 9·9 | 4·2 | 0·7 | 0·2 | 0·1 | 0·1 | 0·5 | 2·2 | 4·9 | 10·4 |
| *South Australia* | | | | | | | | | | | | | |
| Alice Springs | 23 38 | 1·8 | 1·7 | 1·2 | 0·8 | 0·7 | 0·6 | 0·4 | 0·4 | 0·4 | 0·7 | 1·0 | 1·5 |
| Adelaide | 34 56 | 0·7 | 0·7 | 1·0 | 1·7 | 2·7 | 3·1 | 2·6 | 2·5 | 2·1 | 1·7 | 1·1 | 1·0 |
| *West Australia* | | | | | | | | | | | | | |
| Broome | 17 57 | 6·2 | 6·1 | 3·8 | 1·4 | 0·6 | 1·0 | 0·2 | 0·2 | 0·1 | 0·0 | 0·9 | 3·7 |
| Carnarvon | 24 54 | 0·3 | 0·9 | 0·5 | 0·6 | 1·5 | 2·8 | 1·7 | 0·7 | 0·3 | 0·1 | 0·0 | 0·1 |
| Perth | 31 57 | 0·3 | 0·5 | 0·7 | 1·6 | 4·9 | 6·9 | 6·5 | 5·7 | 3·3 | 2·1 | 0·8 | 0·6 |
| Albany | 35 2 | 0·9 | 0·9 | 1·6 | 2·8 | 5·0 | 5·5 | 5·7 | 5·3 | 4·2 | 3·2 | 1·4 | 1·2 |

The distribution of annual rainfall in Australia is shown in Fig. 13.

The climate of Australia favours outdoor occupations (including cricket!), and as over most of the country except the north and east coasts the rainfall is too small and uncertain for large-scale agriculture, sheep-raising is the main industry. Except in the south-east the summers are too hot for sustained physical work by white labour.

New Zealand extends over more southerly latitudes than Australia and, being narrower, is more maritime. The climate of North Island is warm temperate, equable, and rather rainy. The western side of the mountainous South Island is also equable and very rainy, resembling the wetter highlands of western England; by contrast the eastern side is much drier, but the climate is nowhere extreme. As in Britain, summer is prolonged into autumn and winter into spring; the latter is an uncertain season, liable to cold snaps and late frosts. Climatic "accidents" are rare, however, and on the whole the climate of New Zealand is stimulating and very favourable for white people.

# CHAPTER IV

## TEMPERATE CLIMATES OF AMERICA

IN this chapter we discuss the climates of the U.S.A. and the temperate parts of Alaska and Canada, southern Chile, Patagonia, and the Falkland Islands. The Arctic parts of Alaska and Canada are described in Chapter VII.

### THE U.S.A. AND THE TEMPERATE PARTS OF ALASKA AND CANADA

Canada and the U.S.A. lie mainly in the zone of temperate west winds, but Canada and Alaska extend northwards into true Arctic regions, and in the Gulf of Mexico the U.S.A. reach the sub-tropical zone of east winds. North America resembles Eurasia in being a large land-mass with a highly continental climate in the interior and east, but in North America the main mountain ranges run north and south instead of east and west. In Eurasia the prevailing westerly winds carry the influence of the Atlantic Ocean far inland, at times across the whole of Europe and into Siberia. In North America the main mountain system, lying far to the west, forms an almost impenetrable barrier against the west winds from the Pacific. Instead, over most of the continent, north and south winds have free play. There is no permanent winter anticyclone like that which forms every year in Siberia; over most of the continent weather is governed by the passage of a series of depressions and anticyclones from west to east. In front of each depression the winds are southerly, and the influence of the warm Gulf of Mexico is carried far to the north. In the rear of the depressions the wind is north-westerly, and cold waves sweep as far south as the Gulf States and Florida, and even into Mexico and Central America. Stable climates are found only on the Pacific coast of California and in the Great Basin between the Rocky Mountains and the coast ranges of the south-western U.S.A.

In the absence of a permanent winter anticyclone the interior does not suffer from the intense steady cold of Siberia. Instead, the whole eastern and central parts of North America have a regime of violent alternations of warmth and cold, including

the characteristic "cold waves" of winter and "heat waves" of summer. In the U.S.A. the official definition of a cold wave for forecasting purposes is a fall of 20° F. in twenty-four hours (16–18° F. in the south and south-west) to a limiting temperature which varies from 0° F. in the northern interior to 32° F. in the south and south-west, but much greater falls than these are sometimes experienced (see p. 125). When the cold wave is accompanied by strong winds and the ground is covered by loose snow, "blizzards" result (p. 125). Except on the Atlantic and Pacific coasts there is a fairly regular snow cover for at least a month in winter down to about latitude 37° over most of the country. The low winter temperatures stop all outdoor work except lumbering (in which the snow cover facilitates the removal of timber) and the cutting of natural ice.

In summer the hot moisture-laden winds from the Gulf of Mexico carry uncomfortable, sultry conditions far to the north. In the southern U.S.A. the damp heat of many summer afternoons makes factory work uneconomic. The principal manufacturing region lies between this southern hot belt and the northern region, north of about 48° N., where transport is regularly blocked by deep snow and frozen waterways.

The highly variable climate of most of North America has several interesting consequences. It is very stimulating, and probably accounts in large measure for the restless energy of the people of the northern part of the continent. Most of the theories about the effect of weather on work and business originated in the U.S.A., no doubt because of the variability of the weather. In the east of North America from the St. Lawrence to the Gulf of Mexico the rise of mean temperature from north to south is greater than over a comparable distance anywhere else in the world. Communication between north and south is easy, and the products of temperate and tropical regions are readily exchanged. There is also a great volume of holiday travel, south in winter, north in summer.

As a whole North America is a sunny continent, the exceptions being the Pacific slopes north of about 42° N. and the Great Lakes—St. Lawrence region. The rainfall comes in heavier showers on fewer days than in western Europe, the number of raindays being between 80 and 120 over most of the United States (Lake region 170, North Pacific coast 180). Thunderstorms are often violent, bringing heavy rain and

squalls, which in their most intense form become tornadoes (p. 218). Thunderstorms are often accompanied by hail, large hailstones, the size of eggs or larger, doing great damage. At Cheyenne, Wyoming, destructive hailstorms are so frequent that glass-houses are protected by chicken netting. In the western plains and the deserts the thunderstorms are often "dry," the squall winds bringing dust-storms instead of rain. In such storms wire fencing, unless properly earthed at frequent intervals, is very dangerous because lightning, striking any part of it, is conducted along the wire and the whole fence becomes electrified.

The winters vary greatly from year to year. On the Atlantic and Gulf coasts a winter month may be 8–10° F. warmer or colder than the long-period average. On the Pacific coast and in the south-west the range is little more than half as great.

Annual "recurrences" like the stormy and anticyclonic periods of north-western Europe (see p. 102) do not seem to occur to the same extent as in that region, but this may be because they have not been studied in such detail. There is said to be a tendency for the last week of January to be relatively mild (the "January thaw"), followed by a return of cold conditions in the first week of February. Better known is the *Indian Summer*, the counterpart of the "Old Wives' Summer" of Europe. This is a period of calm, sunny days, dry, mild and hazy, which tends to follow the first severe frost and persist for several days. Like the Old Wives' Summer it is irregular in its occurrence; in some years there is no Indian Summer, in others there may be several such periods.

North America is climatically "rich." The great variety of climates gives a corresponding variety of agricultural and forest products, but as similar climates often extend over large stretches of country, for example the "Great Plains," bulk production is facilitated. The mountains of the west, and the great eastward-flowing rivers such as the St. Lawrence system, provide abundant water-power (see p. 33), and where this is absent, on the plains, its place is often taken by wind-power. Finally, the variable stimulating climate of much of the country leads to a high level of production and also, probably, plays a part in the high rate of consumption which necessitates a high standard of living. Against this must be set the magnitude of the climatic catastrophes—blizzards, ice-storms, tornadoes,

hurricanes, great floods, droughts and dust-storms. These climatic "accidents" receive a good deal of notoriety, and the following pages may give the impression that the inhabitants of North America are always liable to be frozen, melted, blown away, washed away, dried up or choked by dust. That would be a gross exaggeration; North America is a large continent and climatic "accidents" are local; probably the majority of the inhabitants go from the cradle to the grave without suffering from any great climatic disaster.

Climatically North America, excluding Mexico and the Arctic belt from northern Alaska to Labrador, may be divided into seven regions:—

(1) Nova Scotia, New Brunswick and Newfoundland.

(2) The large region, originally forested, extending from about 100° W. long. to the Atlantic coast, excluding the most maritime parts of Canada, east of Quebec.

(3) The Gulf States, including Florida, Louisiana, the southern halves of Georgia, Alabama and Mississippi, and south-eastern Texas.

(4) The "Great Plains" region of small or deficient rainfall between about 100° W. long. and the Rocky Mountains.

(5) The northern Plateau from the interior of Alaska to about 42° N.

(6) The southern Plateau and the Great Basin.

(7) The Pacific slopes.

NOVA SCOTIA, NEW BRUNSWICK, NEWFOUNDLAND (Appendix I—Charlottetown, P.E.I.; Halifax, N.S.; St. John, N.B.; St. John's, Newfoundland).

The easternmost provinces of Canada, and Newfoundland, have a rather inhospitable maritime climate with cold, damp winters and cool, foggy summers. The rainfall is heavy and is distributed fairly evenly through the year, with a maximum in late autumn and winter. The coasts of Newfoundland are often blocked by ice in spring (p. 49). The mean temperature varies from about 22° F. in January and February to 60–65° F. in July, with an annual mean of about 42° F. The climate is not suitable for agriculture; the chief industries are lumbering and fishing.

The coasts are very stormy. In late summer and early autumn West Indian hurricanes, after travelling northwards

off the coast of the U.S.A., may strike Nova Scotia. The "cyclone" of August 1873 played havoc with the fishing fleets and is said to have wrecked 1,223 vessels, with a loss of over 200 lives, but hurricanes of this intensity only occur at intervals of many years. In other seasons, especially winter, the depressions of middle latitudes tend to converge on this region from all parts of Canada and U.S.A.; though less intense, they are far more frequent than tropical hurricanes.

EASTERN NORTH AMERICA (Appendix I—*Canada*, Montreal, Ottawa, Quebec, Toronto, Winnipeg; *U.S.A.*, Boston, Chicago, New York, Philadelphia, St. Louis).

The extensive region between about 33° and 55° N. lat. and from 100° W. long. to the Atlantic coast has an extreme climate with rapid changes of weather and a large annual range of temperature. The temperature rises steadily and rapidly from north to south; the following table gives a broad picture:—

TABLE 15.—Mean temperatures, eastern North America.

| | January ° F. | July ° F. | Year ° F. | Range ° F. |
|---|---|---|---|---|
| Canada, 45–53° N. | 8 | 68 | 40 | 60 |
| U.S.A., 45–48° N. | 12 | 66 | 40 | 54 |
| 40–45° N. | 23 | 73 | 50 | 50 |
| 33–40° N. | 36 | 79 | 60 | 43 |
| For comparison, London, 51½° N. | 41 | 63 | 50 | 22 |

The figures for U.S.A. are from R. de C. Ward (1925).

The climate is continental; even the Atlantic coast does not enjoy a maritime climate, because the prevailing winds blow off the land. The Great Lakes have more effect in stabilising the climate than does the Atlantic, and the winter at places like Toronto is much less severe than farther west (*e.g.* Winnipeg). The promontories of the Lakes region have a very favourable climate; the Lakes prevent late frosts and these districts are famous for growing fruit and tobacco.

The open plains give free play to the winds, which blow steadily though not strongly. The average wind speed is 8–10 m.p.h. over much of the area, exceeding 12 m.p.h. in the Great Lakes region (Chicago is known as "the windy city"), the St. Lawrence valley and the more exposed parts of the Atlantic coast.

Rainfall in the east is plentiful and well distributed through

the year, but it decreases westwards from 40–50 inches on the coast to about 20 inches in 100° W., where it falls mainly in summer. North of about 37° N. the winter precipitation comes mainly in the form of snow, and a regular snow cover forms (Fig. 8). The depth of loose snow exceeds 8 feet south-east of the St. Lawrence and south of Lake Superior, and is 2 or 3 feet over all New England and the northern part of the region. Severe snowstorms occur, some of which have become historical because of the interruption of communications. Descriptions of some of these are given by C. F. Brooks (1935). On 11th–14th March 1888 more than 3 feet of snow fell in three days and the gales piled up drifts 40 feet high. On 11th–14th February 1899, 44 inches fell in southern New Jersey. On 19th–20th February 1934 Connecticut had 2 feet of wet, sticky snow, which was frozen hard on the streets and railway tracks by a succeeding cold wave. In the same winter snow fell to a depth of 8 feet in eastern Maine, and 15 feet deep on the south shore of the Gulf of St. Lawrence.

"Ice storms" (glazed frosts, see p. 47) may be very severe in the northern part of the region. In November 1921 freezing rain fell for three days with a north-east wind in Massachusetts. Telephone wires had a coating of ice 2 inches thick and the supporting poles were snapped in hundreds. Communications and electric supply were interrupted for days. An even worse ice storm occurred in the Great Lakes region on 21st February 1922.

The characteristic winter weather is an alternation of severe cold waves and moderate warm spells. The cold waves are sometimes accompanied by strong winds which raise the surface snow in blizzards (see p. 125). Temperature may fall 30–40° F. in twenty-four hours. This kind of weather is invigorating to those in good health, but the extremes of damp cold and the artificially hot dry air of buildings induce respiratory diseases, which are especially prevalent in late winter and early spring. In eastern U.S.A. there are three or four severe cold waves in an average year.

Spring is an uncertain season, periods of abnormal warmth alternating with cold spells and destructive frosts. In New York temperature in March has ranged from 80° to 3° F., and in April from 91° to 12° F. In the St. Lawrence and lower Great Lakes the season is rather foggy. Spring is short, especially in the northern interior, where it is practically limited to April.

The months of January to May bring the worst *floods*, especially in the valleys of the Ohio and Mississippi. The Ohio, because of its narrow valleys with steep gradients and the heavy rainfall on the Alleghenies, is especially liable to flooding. The floods result from heavy rain on frozen or waterlogged soil. The rain is due to warm, moist air from the Gulf of Mexico meeting cold air from the north-west; melting snow rarely plays much part in causing floods. An exception was the record Pittsburgh flood of March 1936, which was due to a combination of intense rain, the melting by a warm wind of a deep snow cover on the New England hills, and frozen ground which prevented the absorption of the water. The most disastrous flood was that at Johnstown, Pa., in May and June 1889, when 9·8 inches of rain fell in thirty-one hours. Under the pressure of flood water a dam burst, and about 9,000 people were drowned. The worst occurrence of recent years was the Kentucky flood of January to February 1937, when the River Ohio rose 29 feet above normal flood level. The rainfall was not excessive on any one day, but was widespread and very persistent. A list of great floods in the U.S.A., and a discussion of their causes, is given by C. F. Brooks and A. H. Thiessen (1937).

Summer is generally a quiet, hot season. Its chief characteristic, especially in the east and the Great Lakes region, is the combination of high temperature and high humidity, which is very enervating. Heat waves occur with a light southerly wind and clear skies, the days becoming steadily hotter. The high humidity keeps the diurnal range of temperature small, so that during heat waves the nights are especially unpleasant. Diarrhœa is a frequent complaint, especially among children, and deaths sometimes occur from heat prostration. These heat waves are most frequent in the Mississippi Valley, but occur as far north as Montreal and Quebec. On the hottest days the sea breeze provides some relief within a few miles of the Atlantic coast, and to a lesser extent the lake breeze on the shores of the Great Lakes. The coast of Maine suffers from summer fogs which interfere with the summer holiday resorts.

Summer is the rainy season over the whole interior, much of the rain coming in severe thunderstorms. These are often accompanied by squalls which may do considerable damage and are sometimes reported as "tornadoes." In spite of the

heavy rain the season is marked by abundant sunshine, the rain being intense and of correspondingly short duration.

The western and central parts of the region sometimes experience severe droughts such as that which began in 1930 and returned in 1934. The soil was dried out and blown away in great clouds of dust. Although the deficiency of rainfall was probably no greater than has occurred at intervals of thirty or forty years for many centuries, the increasing population and the withdrawal of ground water by pumping from wells and drainage of swamps, has accentuated the consequences.

In late summer and autumn West Indian hurricanes (see p. 225) occasionally travel up the coast, bringing gales and heavy rain, which may result in disastrous floods in the eastern U.S.A. Examples were the floods of July 1916, due to heavy rain on the southern Appalachians, the floods in New England and New York in November 1927, when 8·77 inches of rain fell in a day in Vermont, and the New York flood of July 1935, with 9·0 inches in a day. In the 1927 flood there were 8–10 feet of water in the business section of Montpelier, Vt., and at White River Junction the Connecticut rose 29 feet in twenty-four hours. As a rule summer floods are less serious than those of winter and spring because, although the rainfall is heavier, it is also more local, the ground is drier and there is a good deal of vegetation to retard the run-off. The West Indian hurricanes also bring severe gales to the Atlantic coast, wind speeds reaching 75–90 m.p.h. The most disastrous of these swept the populous coasts of Long Island and southern New England on 21st September 1938. The damage to buildings, trees, power lines, highways and shipping is estimated by I. R. Tannehill (1944) as between 250 million and 330 million dollars; the loss of life was about 600. At Blue Hill Observatory, Massachusetts, the highest wind speed was 121 m.p.h. over five minutes, with a peak of 186 m.p.h.

THE GULF STATES (Appendix I—Charleston, Galveston, Key West, Miami, New Orleans).

The States of Florida and Louisiana, south-eastern Texas and the southern halves of Mississippi, Alabama and Georgia form a southward extension of the eastern province of the U.S.A. Owing to the influence of the warm Gulf of Mexico the temperatures are much higher, especially in winter, the weather changes are fewer and less violent, and the rainfall heavier.

R. de C. Ward (1925) places the northern boundary along the annual isotherm of 65° F. He gives as the average temperature over the whole area: January, 51° F.; July, 82° F.; Year, 70° F.; Range, 31° F. The region is mainly agricultural, producing cotton and tobacco as well as fruit and early vegetables for northern markets. The main industry is tobacco processing.

In spite of the general mildness of the winters cold waves sometimes penetrate as far as the Gulf Coast, bringing killing frosts even to Galveston in Texas, but southern Florida generally escapes. Key West, off the southern tip of the peninsula, has a tropical climate. The lowest temperatures recorded at stations from north to south are: Wilmington, N. Car. (34° N.) 5° F.; Charleston (33° N.), 7° F.; New Orleans (30° N.), 7° F.; Jacksonville, Fla. (30° N.), 10° F.; Tampa, Fla. (28° N.), 19° F.; Key West (24½° N.), 41° F. The effect of the short stretch of ocean between the mainland of Florida and Key West on the minimum temperature is very notable. Snow falls occasionally as far south as northern and central Florida in the east and over most of Texas in the west, but very rarely lies so far south. A great snowstorm disorganised traffic in Texas in December 1929 when 2 feet of snow fell at Hillsboro (32° N.) and 2 inches even on the coast. Snow falls regularly in the interior north of about 30° N.

The spring floods of the Ohio and upper Mississippi sometimes extend down the river to New Orleans. The most notable example was the flood of April 1927, when prolonged and violent rains over the whole Mississippi basin raised the level of the river to such a height that the levees were breached in many places. No less than 28,573 square miles of land were flooded, and the damage was estimated as 284 million dollars, but the loss of life was comparatively small, thanks to the flood warnings. In addition to thunderstorms, from 10th–14th April, no fewer than eighteen tornadoes were reported.

It is of interest that one of the earliest records of the Mississippi valley describes a great flood in March and April 1543, which held up de Soto's expedition.

The summers are long, hot, humid and enervating. Summer is the rainy season, in which the bulk of the annual rainfall of 50–60 inches falls, largely in severe thunderstorms. On the Texas coast the summer is hotter and drier than in Louisiana, and the rainfall maximum is delayed until autumn.

The wind speeds are generally light (about 8 m.p.h., 10 m.p.h. on the coast), but the whole region is subject to hurricanes in autumn which are much more severe than farther north. They move in from east or south-east in about 25° N. lat. and usually turn northward up the Atlantic coast, some distance offshore, to Nova Scotia. Some, however, penetrate the Gulf of Mexico and either strike the coast of Texas or turn north along the central valleys, breaking up over the land with torrential rains. The one which devastated Galveston on 1st–12th September 1900 is said to be the worst storm on record in the United States. The wind speed was much above 100 m.p.h. (the anemometer was blown away), and raised the level of the sea by 15–20 feet, flooding the whole of the island on which Galveston is built. Nearly half the houses were destroyed, with property worth 30 million dollars, and more than 6,000 people were killed. A hurricane struck Louisiana on 20th September 1909, the storm wave flooding New Orleans, again with great loss of life and property. Still more severe was the storm of 29th September 1915, when the wind reached 140 m.p.h. and a large number of buildings in New Orleans and neighbouring towns were wrecked. In the famous Florida hurricane of 18th–19th September 1926 the wind between Miami and Palm Beach reached 130 m.p.h. An eighteen-story skyscraper was twisted so badly that it had to be demolished. The damage to property exceeded 100 million dollars, 327 people were killed and more than 6,000 injured. Most of the loss of life was due to the breaking of a dam separating the small town of Moore Haven from Lake Okeechobee. In all these hurricanes the loss of life and of shipping would have been much greater but for the warnings issued by the U.S. Weather Bureau.

THE "GREAT PLAINS" BETWEEN 100° W. AND THE ROCKY MOUNTAINS (Appendix I—*Canada*, Edmonton; *U.S.A.*, Denver).

This elevated region, rising westwards from about 2,000 feet to a general level of over 6,000 feet, has a very continental climate. The mean temperatures are about:—

| | January ° F. | July ° F. | Year ° F. | Range ° F. |
|---|---|---|---|---|
| Canada, 49–54° N. . | 8 | 65 | 40 | 57 |
| U.S.A., 42–49° N. . . | 15 | 69 | 45 | 54 |
| 30–42° N. . . | 35 | 79 | 57 | 44 |

The figures for U.S.A. are from R. de C. Ward (1925).

The rainfall is almost everywhere less than 20 inches a year, so that without irrigation agriculture is very precarious. The whole region is open to the winds, and in winter cold waves, snowstorms and blizzards sweep over the country, sometimes penetrating as far as New Mexico and Texas. Temperature is very variable and may rise or fall 50° F. or more in twenty-four hours. In the blizzard of 12th January 1888 in the Dakotas, two or three hundred people, caught in the open, were unable to find their way to shelter and died of exposure; thousands of cattle were lost. The wind speed exceeded 50 m.p.h., with temperatures falling from 30° F. to −20° F. in five hours. The word "blizzard" comes from the German *blitzartig*, lightning-like, and aptly describes the suddenness of onset of these storms. A similar visitation occurred in North Dakota and Minnesota on 13th–14th February 1923, and interrupted train services for over a week. South of 40° N. the winter snow cover is irregular in occurrence.

The opposite of the blizzard is the warm, dry *chinook*, which blows from the south-west or west and descends the slopes of the Rocky Mountains. Under its influence temperature rises rapidly, sometimes 20–40° F. in a quarter of an hour. At Medicine Hat, Alberta, temperature has risen 70–80° F. in a few hours, and the range between the highest and lowest recorded temperatures exceeds 100° F. in each month from January to April. March has experienced a maximum temperature of 84° F. and a minimum of −38° F. At the onset of a chinook, before the cold air has all been blown away, the temperature often fluctuates wildly for some hours, until the warm wind sets in steadily. It often skips a belt of about 100 miles wide at the foot of the mountains, which remains as a pocket of cold air. Under the influence of the chinook the snow cover disappears rapidly by melting and evaporation and the ground soon dries out. This enables the cattle to feed, and in fact without the chinook cattle raising would be very difficult. It also helps to keep the railways from being blocked by snow, but the dryness brings the risk of forest fires.

Except in the far north, summer is intensely hot, maxima exceeding 100° F. over almost the whole region, in spite of the general elevation. It is made up of long spells of settled fine weather and drought interrupted by occasional violent thunderstorms. The hot waves are more bearable than those of the east

because the air is very dry, but they are more damaging to crops. The worst feature is the "hot wind," the summer equivalent of the chinook, which descends from the mountains in local blasts of hot air a few miles wide, raising clouds of dust. "Hot winds" occur from June to September, most often in July and August. They cause great irritability and insomnia, and have been known to interrupt rail traffic by springing the rails. They are most severe in Colorado and Wyoming.

The winds have an average speed of 10–14 m.p.h., and being steady are admirable for driving windmills. Over the open plains thousands of windmills are in use for pumping water for irrigation and for generating electricity.

THE NORTH PLATEAU REGION, ALASKA TO IDAHO AND OREGON (Appendix I—*Canada*, Dawson).

This region consists of a number of steep, narrow valleys between the Rocky Mountain Divide and the Coast Ranges. It is not of great economic importance. The interior of Alaska and north-western Canada have a continental climate with long severe winters and short, hot summers. The snow cover reaches a thickness of 3–8 feet, but melts quickly in spring. The ice in the Yukon breaks up in May.

Rainfall in the valleys is light, but snowfall on the peaks is very heavy, especially in British Columbia, Washington and Oregon. Here the summers in the valleys are hot and dry, and irrigation produces large fruit crops.

THE SOUTH PLATEAU (Nevada, Utah, Western Colorado, Arizona, Western New Mexico, interior of California) (Appendix I—Salt Lake City, Yuma).

The wide, lofty plateau between the Rocky Mountains and the Sierra Nevada has an extreme climate. According to Ward the mean temperature over relatively low ground ranges from 51° F. in January to 91° F. in July, with an annual mean of 70° F., but owing to the great variations of elevation and exposure such figures have little meaning. Rainfall is generally between 5 and 15 inches a year, sometimes less, and it falls mainly in short, heavy showers in summer, when evaporation is intense. On the mountains the rainfall is heavier and supplies water for irrigation, producing large crops. Land which cannot be irrigated is desert or semi-desert and is valueless except for minerals. The winter snowfall on the higher slopes of the Sierra Nevada and Cascade Ranges amounts to 30–40 feet uncom-

pacted, but it is drifted and packed by the wind and melts slowly, maintaining a good supply of water in the rivers. Snow sheds are necessary on the railways, and these are costly to build and maintain. In summer the occasional heavy rains cause landslides and washouts.

The southern Plateau escapes the storms of higher latitudes and the winds are generally light. The dry, clean air is health-giving, and Colorado has a number of famous health resorts on the slopes above the valleys. The higher desert regions suffer from occasional strong dusty winds. The district includes the famous Death Valley in south-east California, a narrow depression 276 feet *below* sea-level, which has a mean July temperature of 101° F. and has recorded a maximum of 134° F., the second highest in the world. But in winter Death Valley is now a health resort.

THE COASTAL SLOPES OF THE PACIFIC (Appendix I—*Alaska*, Sitka; *Canada*, Victoria, B.C.; *U.S.A.*, Seattle, San Francisco, Los Angeles).

The narrow coastal strip which runs from Alaska to California is the only part of North America in which the climate resembles that of western Europe. The rainfall comes mainly in winter, and decreases from north to south. The winters are mild along the whole stretch of coast, the January mean temperature rising only from 32° F. at Sitka to 54° F. at Los Angeles. From Oregon northwards the weather is stormy and very rainy on the coast. Extraordinary wind speeds are recorded on the bluffs of places like Tatoosh Island, where gales of 33 m.p.h. or more are experienced on ninety-six days from October to March, and the average wind speed for the whole year is nearly 20 m.p.h. The inland valleys are sheltered. North of San Francisco severe winter storms bring gales of 50–90 m.p.h. In January 1921 a very heavy storm struck Washington and Oregon. At the mouth of the Columbia River the wind averaged 126 m.p.h. for five minutes and reached 150 m.p.h. in a gust. Enormous damage was done to standing timber.

Snow falls regularly in winter north of 45° N., and occasionally as far south as Los Angeles. In Alaska it reaches depths of 4–12 feet, but in western U.S.A. it does not lie and is not important.

Summer is a quiet settled season with moderately high temperatures. The July mean ranges only from 53° F. at Sitka

to 70° F. at Los Angeles. The nights are cool and the afternoons warm. From Oregon northwards there is some cloud and rain, but California is the "land of sunshine"—and evaluates it in dollars and cents. Irrigation is necessary for raising crops, and the water for this is provided by the snows on the mountains. The regular sunshine favours the film industry and is also important for fruit drying. In spring and early summer California is subject to a very hot dry wind from the desert plateaus to the north or north-east, the Norther or Santa Ana, which resembles the "hot wind" of the Great Plains. It brings temperatures as high as 120° F. in June, and the heat and dryness damage fruit trees and increase the risk of fires. It also brings clouds of dust which are thick enough to impede traffic.

California is generally rainless in summer, but at long intervals "cloudbursts" occur, and it is worth recording that at Campo, San Diego, 11·5 inches of rain fell in an hour on 12th August 1891. This is the world's record for an hour's rainfall. On 25th August 1925, during a thunderstorm in the San Joaquin valley, a flash of lightning struck an oil reservoir and caused a great fire, which cost insurance companies more than a million dollars.

The Pacific coast is very foggy in summer. The U.S. definition of "dense fog" is visibility less than 1,000 feet, and this occurs on forty or more days a year along the whole coast, mainly from July to September. San Francisco is famous for its fogs, and it is to escape them that the city has extended eastwards to less foggy and chilly sites in Berkeley and Oakland.

The climate in San Francisco is most strange. It lies at the only gap in the Coast Range, separating the wide Sacramento and San Joaquin valleys from the Pacific, and in summer a very strong, steady wind pours through the gap, an intensified sea-breeze. This keeps the temperature down and brings in the sea fog. The mean and highest recorded temperatures are as follows:—

| | Jan. | Feb. | Mar. | Apr. | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mean, ° F. . | 50 | 52 | 54 | 55 | 57 | 58 | 58 | 59 | *61* | 60 | 56 | 51 |
| Highest . | 78 | 80 | 86 | 89 | 97 | *100* | 98 | 92 | *101* | 96 | 83 | 74 |

As a local saying has it, overcoats are worn in summer and the lilies bloom in December.

### SOUTHERNMOST SOUTH AMERICA; FALKLAND ISLANDS

South America extends from north of the Equator into high southern latitudes. Brazil and the northern countries are considered under Tropical Climates (Chapter VI), Paraguay, Uruguay and most of the Argentine and Chile are sub-tropical (Chapter V). There remains only southern Chile, south of about 35° S., Patagonia, and the Falkland Islands.

SOUTHERN CHILE (Appendix I—Valdivia, Punta Arenas).

The northern half of Chile has too little rainfall, the southern coastal regions too much. The annual totals increase from 5 inches in 32° S. to 30 inches in 35° S., 40 in 37°, 60 in 38° and 80 in 39° S. From Valdivia in 39° S. the rainfall exceeds 80 inches over the coast and islands, and from 42° S. there is a narrow coastal strip with more than 100 inches a year, exceeding 200 inches in places. The region is a vast morass, and for 900 miles the woods are so wet that it is impossible to set a fire for clearing without constant relighting. The prevailing winds are westerly and very stormy (the "roaring forties"), and these keep the temperatures moderate.

PATAGONIA has a dry continental climate, with hot days but cool nights in summer, and cold winters. The only well-watered regions are in the valleys of the Cordilleras in the west, where there are a number of agricultural settlements. In the south the whole country is dominated by the blustery west wind. In spite (or because) of its severity the climate is healthy and invigorating.

THE FALKLAND ISLANDS (Appendix I—Stanley) are cool, oceanic and so windy that the inhabitants are said to develop a characteristic walk. The western slopes are very inhospitable; on the east there is some rough pasture, but the sunlessness and cold summer make the islands unsuitable for agriculture. The climate is very healthy.

# CHAPTER V

## SUB-TROPICAL CLIMATES WITH SUMMER RAINFALL

NEAR the northern and southern tropics ($23\frac{1}{2}$° N. and S.) the sun is nearly overhead for some hours at midday in summer, the weather is hot and there is a good deal of convection, so that summer is generally the rainy season. Where moisture-laden winds blow freely off the oceans the rainfall is considerable even on low ground; where mountains receive the full impact of these moist winds it is torrential. Winter by contrast is generally cool and dry. In Asia and to a less extent in West Africa and northern Australia there is a regular alternation of winds blowing from the oceans far into the interior of the continents in summer, and from the continents to the oceans in winter. These are the monsoons which give rise to a special type of climate. Monsoons are most developed in southern and eastern Asia (India, Burma, Indo-China, China, Japan), not only because of the size of Asia, but also because of its rugged topography, which accentuates both the cold of winter and the heat of summer in the mountain-ringed basins. The West Indies, on the other hand, show the "pure" inter-tropical and sub-tropical climate almost undisturbed by the effect of large land masses. South Africa, Madagascar, Mexico and Central America are intermediate in type.

### MONSOON CLIMATES OF ASIA

The typical monsoon climates are found in southern and eastern Asia. There are three main types: (1) southern and south-eastern Asia; (2) China; (3) Japan.

INDIA, BURMA, INDO-CHINA (Appendix I—*India*, Allahabad, Bangalore, Bombay, Calcutta, Delhi, Karachi, Lahore, Madras, Peshawar, Simla; *Burma*, Mandalay, Port Blair, Rangoon; *Indo-China*, Phu-Lien, Saigon; *Siam*, Bangkok).

This region, extending from the Arabian Sea to the Pacific Ocean, from 30° N. nearly to the Equator, and sheltered from north winds by almost continuous high ground, has a generally

warm climate and a well-developed alternation between north-east winds in the northern winter and south-west in the northern summer. The average temperature on low ground is above 75° over the whole region and exceeds 80° over all peninsular India except the west coast and all the more southerly parts of Farther India (Burma, Siam and Cambodia). In the southern and eastern parts of Farther India the air is moist, the relative humidity exceeding 80 per cent. in many coastal regions; other humid areas are the Assam Hills and the south-west coast of India, but over most of India the humidity is moderate and in Rajputana it is less than 50 per cent.; this region is comparatively dry throughout the year.

The distribution of rainfall shows a very wide range, from 2 inches a year in north-west India to more than 400 inches near Cherrapunji in the Khasi Hills of Assam, where the average monthly distribution is (inches):—

| Jan. | Feb. | Mar. | April | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0·5 | 3·1 | 9·1 | 31·7 | 43·5 | 94·2 | 101·8 | 82·9 | 34·9 | 19·5 | 2·4 | 0·4 |

The heaviest rainfall in twenty-four hours was 40·8 inches in June 1876. Another area of heavy rainfall is along the Western Ghats, between Bombay and Cochin and a third is the coast of Burma. In north-west India a large area, extending to the coast east of Karachi, is true desert except where it can be irrigated. In the interior of Burma, and in Siam and Indo-China, the rainfall is generally moderate. In Annam the rainfall is more evenly distributed through the year than in India.

The number of raindays is not large because the rainfall is compressed into a short monsoon period. Exceptionally heavy falls are frequent; on seven occasions falls of more than 30 inches in a day have been recorded in different parts of India.

The alternation of monsoons dominates the life of India. Two seasons are distinguished, the dry season and the "rains," but the dry season is divided into the "cold weather" and the "hot weather." The cold weather lasts from the middle of December to the end of February, and on the low ground in the north is the pleasantest season of the year for Europeans, but Indians find the mornings too cold for comfort. Temperature is moderate, the whole region being below 80° F. in January; in northern India the average is below 60°, but

southern India is never really cool. The daily range is large, exceeding 25° over the greater part of the interior and reaching 30° in many parts; hence though the days are hot the nights are cold. Temperatures below 45° have been recorded over the whole northern half of the region, and in north-west India frosts are common. Rainfall is very slight except in the north-west of India, where the cold-weather storms bring a small total, and on coasts exposed to north-easterly winds, such as the east coast of the Isthmus of Siam, which has its rainy season in November and December.

The "hot weather" includes March, April and May, and is much less pleasant and more unhealthy than the winter. Temperature rises rapidly, and in May averages 93° F. in central India. The daily range is greater than in January, and very high maxima are recorded, above 110° over north-west and central India and in the interior of Siam. In the Punjab the heat is aggravated by dust from the deserts to the west, and houses must be closed against it after sunrise, or sheltered by grass mats kept moist.

In India the average duration of the south-west monsoon is: Bombay, 5th June to mid-October; Bengal, 15th June to late October; North-west Province, 25th June to 30th September; Punjab, 1st July to mid-September. With the onset of the monsoon rains the whole character of the climate changes. Except in north-west India temperature falls, and on the west coast of India and in southern Siam it is less than 80° F. More important is the decrease of the daily range, which is now less than 20°, so that while the days are cooler than in May the nights are not. Except in the north-west, the relative humidity is above 80 per cent. in most districts and exceeds 90 per cent. in parts of the Western Ghats and Burma. Cloudiness is very great, again excepting north-west India. In the rainiest areas rain falls nearly every day, but over most of the country the monsoon is broken by short periods of fine weather with rising temperature, which frequently end in thunderstorms. The rainy season is enervating, but not unhealthy; it is very destructive of materials by corrosion and moulding.

October and November in India are marked by lighter and more variable winds and decreasing temperature, cloudiness and rainfall in India. The excessive moisture on the ground and in the air, pools of water, and decaying vegetation under a hot

sun make this season the least healthy and most liable to contagious diseases of the year, especially in the plains of northern India; damage by corrosion and moulding is even more rapid than during the rains. It is also the period during which severe cyclonic storms are most frequent in the Bay of Bengal. During the rainy months of June to September there are numerous moderate or weak storms, but severe cyclones are rare. The earlier transition period in May is a secondary maximum of severe cyclones; May, October and November account for 55 per cent. of such storms. They mostly travel north-west or north, causing heavy rainfall on the coast, and hurricane winds which do much damage to property. If a storm comes at high tide a huge mass of water may be driven over the low ground, with much loss of life. These cyclones are the most destructive phenomena in India. As examples: in the terrible Backergunge cyclone of 1st November 1876 in Bengal a tidal wave struck the coast, about 100,000 people were drowned and all the crops were destroyed, causing famine and pestilence which were estimated to have cost a further 100,000 lives. Even worse was the cyclone of 11th–12th October 1737, when a storm-wave 40 feet high swept up the Ganges and drowned about 300,000. Another storm-wave in 1864 devastated the same region. In the Octobers of 1881 and 1924 typhoons caused great devastation along the coast of Annam.

At intervals of a few years the monsoon rains of India are deficient and the country suffers from severe famine, but good government and relief measures have largely overcome the effects of such seasons. Several irrigation projects have been carried out to relieve famines or to irrigate desert regions, and have brought excellent returns. Large areas of the lower Indus valley, formerly desert, have been irrigated by canals. The heavy rainfall of the seaward side of the Western Ghats mostly runs to waste in the Arabian Sea, while the Deccan to the east is dry, and in at least one case a river (the Periyar) has been diverted to flow eastwards through a tunnel in the mountains. Also, in order that relief measures may be taken in time, a great deal of effort has been put into attempts to forecast, several months ahead, whether the monsoon rainfall of the different parts of India will be above or below the average.

The following data, extracted from the *Climatological Atlas of India* and the *Indian Meteorological Memoirs*, show the annual

variation of the various climatic elements over the Indian land area.

TABLE 16.—Climate of India

| | Jan. | Feb. | Mar. | April | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. | Year |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mean Temperature ° F. | 67·5 | 71·6 | 79·2 | 86·0 | 88·7 | 86·6 | 83·5 | 82·5 | 82·5 | 80·0 | 73·6 | 68·0 | 79·0 |
| Daily Range ° F. . | 23·0 | 23·5 | 24·0 | 23·0 | 20·4 | 15·7 | 12·3 | 12·1 | 14·0 | 18·6 | 21·2 | 22·3 | 19·2 |
| Relative Humidity % . | 63 | 58 | 54 | 52 | 55 | 67 | 79 | 81 | 79 | 70 | 65 | 64 | 66 |
| Vapour Pressure, mb. . | 14·2 | 14·7 | 17·0 | 19·5 | 22·8 | 26·6 | 28·6 | 28·5 | 27·3 | 22·6 | 17·5 | 14·8 | 21·2 |
| Cloudiness, tenths . | 2·2 | 2·3 | 2·3 | 2·6 | 3·3 | 5·6 | 7·1 | 6·9 | 5·1 | 3·1 | 2·3 | 2·2 | 3·7 |
| Rainfall, inches . | 0·5 | 0·5 | 0·7 | 1·2 | 3·1 | 7·9 | 11·2 | 10·3 | 7·0 | 3·3 | 1·3 | 0·5 | 47·5 |
| Raindays . . | 1 | 1 | 1 | 2 | 4 | 9 | 12 | 12 | 8 | 4 | 2 | 1 | 57 |

The northernmost parts of India, especially the high-level valleys such as Kashmir, are almost temperate, and are probably no less suitable for Europeans than are the Gulf States of the U.S.A., provided that reasonable sanitary precautions are taken and the head is kept covered against the sun in the hottest parts of the day. Bengal, the Ganges valley and farther south in India, and the central and southern parts of Burma and Indo-China, are too hot, and in many places too humid, for whites to maintain their health and efficiency over a number of years without periodic recuperation in a hill station or preferably in a temperate climate. The loss of efficiency is probably due as much to tropical diseases, which can be avoided by care and sanitation, as to the direct effect of climate, except that the latter weakens the resistance to disease. But the necessary precautions are expensive, so that the cost of living for whites is high. It is also difficult to raise healthy white children in south-east Asia, and children must be sent home to Europe at an early age. Apart from this, life in the more civilised parts of south-east Asia is pleasant enough, especially in the cold season.

CHINA, MONGOLIA, KOREA (Appendix I—*Mongolia*, Charbin, Urumtsi; *Manchuria*, Mukden; *Korea*, Jinsen (Chemulpo); *China* (North), Tsientsin; (Central), Shanghai, Nanking, Chungking; (South), Canton, Hong Kong).

The climate of China is extreme, with cold dry winters and warm humid summers. The winter temperatures near the coast are the lowest for their latitudes anywhere in the world; in western China the winters are less cold because of the shelter afforded by the mountain ranges. The basin of Szechwan is

especially favoured. Climatically the region falls into three zones:—

(1) North China, Mongolia, Manchuria, Korea.
(2) Yang-tse Valley.
(3) South China.

(1) Most of the northern zone has very cold rainless winters, with temperature falling well below 0° F. Strong dry north-westerly winds prevail, raising clouds of dust which are very troublesome in Peking, and sometimes interferes with navigation on the coast. The Chinese take advantage of the wind by fixing sails to their wheelbarrows. Warm clothing is essential in spite of the bright sun. The rivers are frozen and a snow cover forms every year. The lowest recorded temperatures are (° F.): Charbin (46° N.), −36; Hsingking (Manchukuo, 44° N.), −33; Si-wan-tse (41° N.), −28; Taiyuan (38° N.), −21; Tsientsin (39° N.), −3; Tsinan (37° N.), +1. In Korea the cold is somewhat moderated by the neighbourhood of the sea, the lowest minima being −6° F. at Jinsen in the north-west and +7° F. at Fusan in the south-east. Eastern Korea also has some rain in winter, light in the north, moderate in the south.

Summer lasts from May to September and is warm and humid, but not hot enough to be enervating; there is some rain from April or May to October, but more than half the annual total falls in July and August. In Manchuria in August the rain is almost continuous with frequent thunder, and the ground is flooded. The winds are south-easterly, mostly light or moderate. In the east the rainfall is sufficient for agriculture, but the western part of the zone is arid and much of it is desert. There is no real spring; the change from winter to summer is rapid. In some years the rainy season is delayed and hot dry west winds blow from March until June; these droughts do great damage to the growing crops. The river Hoang-Ho rises rapidly in summer and at intervals breaks its banks and over-flows the surrounding country, causing great disasters.

In spite of the dependence of the country on agriculture, the great variability of rainfall from drought to flood, and the range of flow of the large rivers from winter to summer, there is only local irrigation in China, and nothing on the scale of the

great enterprises of the Nile Valley. Local irrigation is mostly practised in the rice-growing districts of the south. The density of the population and the long courses of the rivers cause the water of the latter to be impure and unfit to drink without purifying or boiling. Since boiled water is rather unpalatable, this may be the reason why the Chinese have the universal habit of taking their fluid in the form of tea.

(2) The Yang-tse valley has cold winters, with about three months below freezing, but much milder than those of the northern zone. Winter is the dry season, but there is some rain in all months; the winds are lighter and, though most frequent from north, they are more changeable than in Manchuria and Mongolia. The sheltered basin of Szechwan has short winters with hardly any frost but almost continuous cloud, making them very depressing. The lowest minima are (from the coast inland, ° F.): Shanghai, 10; Nanking, 8; Hankow, 13; Ichang, 20; Chungking, 29. The summers are hot, with a mean temperature exceeding 70° F., and in the plains they are humid and enervating; July, August and September are the rainiest months. Szechwan is especially hot, the mean temperature of Chungking exceeding 80° F. from mid-June to the end of August, while the maximum has reached 111° F. The mountain basins are subject to occasional severe thunderstorms, with heavy rain causing floods. The rainfall is much more reliable than in the northern region and severe droughts are unknown.

(3) Southern China has generally mild dry winters with occasional cold spells when northerly winds from Mongolia extend to the south coast, bringing temperatures below 35° F., but the east coast is less subject to them. Thus the lowest recorded temperatures are 32° F. at Hong Kong, but 39° F. at Amoy. There is little rain from December to February, though no month is rainless and the winter is bright and sunny (the name Yunnan means "south of the clouds"). Frost and snow are very rare on low ground, but are frequent on the mountains which make up most of the region. Summer is hot and rather enervating in the plains, but healthy and pleasant in the mountains; the deep mountain valleys are, however, very unhealthy. The rainfall is very heavy in June, July and August.

Between June and September the south-eastern coast is

occasionally visited by typhoons (see p. 225), in which the wind speed may exceed 120 m.p.h. and the rainfall amount to 20 or more inches in a day. The typhoon which sank the *De Witte* in August 1901 crossed Fukien and Chekiang. In August 1922 a typhoon struck Swatow, and a great wave washed away the greater part of the city. In a typhoon which passed close to Hong Kong in August 1923 the anemometer recorded a gust of 127 m.p.h. These typhoons usually break up soon after crossing the coast, with thunderstorms and torrential rain. On 19th July 1926, in such circumstances, 20·4 inches of rain fell at Hong Kong in nine hours (4 inches in one hour); the city was flooded and considerably damaged. In another typhoon the centre of which passed over Hong Kong on 2nd September 1927, the anemograph showed a maximum velocity of 167 m.p.h., but the rainfall was only 5·9 inches. A good deal of damage was done and the typhoon wave caused many deaths.

JAPAN, FORMOSA (Appendix I—*Japan*, Nagasaki, Naha, Nemuro, Otomari, Tokyo; *Formosa*, Taihoku).

The northern part of Japan (Hokkaido and northern Honshu) has severe winters. The temperature is not so low as on the opposite mainland, but the western sides and the mountains have very heavy snowfall, depths of 20 feet or more burying the mountain villages and making all outdoor work impossible. The east coast is clear and dry. Southward the winters become much warmer, and the islands of Shikoku and Kyushu are almost sub-tropical, but even Formosa experiences occasional cold days. The lowest recorded temperatures are (° F.): Otomari (Sakhalin, 46½° N.), −27; Nemuro (43½° N.), −9; Hakodate (41° N.), +2; Niigata (38° N.), 15; Tokyo (35½° N.), 17; Nagasaki (32½° N.), 22; Taihoku (Formosa, 25° N.), 32. The mildest winters are in the Liu-Kiu Islands, the lowest temperature at Naha (26° N.) being 41° F.

Summer is warm and humid over the whole region; in the north and at high levels it is a pleasant, invigorating season, but over most of Japan and in Formosa it is hot and enervating.

On the western side of Japan and on the north-western tip of Formosa (Keelung) the rainfall is heavy throughout the year, with a maximum in winter where the prevailing north-west wind blows onshore. The eastern and southern coasts have

only moderate rains in winter and heavy rains in summer; as shown by the following monthly averages in inches:—

| | Jan. | Feb. | Mar. | April | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Niigata (West Coast) . | 7·6 | 5·0 | 4·3 | 4·2 | 3·6 | 5·2 | 6·3 | 4·9 | 7·6 | 6·1 | 7·3 | *9·3* |
| Yokohama (East Coast) . | 2·8 | 3·1 | 5·1 | 5·5 | 6·0 | 7·1 | 6·7 | 8·7 | *10·3* | 8·5 | 4·1 | 2·7 |
| Nagasaki (South Coast) . | 3·0 | 3·3 | 5·2 | 7·5 | 6·7 | *12·8* | 9·4 | 6·8 | 8·6 | 4·8 | 3·5 | 3·4 |

The heaviest rain in the east comes in the autumn and is partly associated with the passage of typhoons; there is a secondary maximum in early summer. On the south coast and in the Liu-Kiu Islands the wettest period is June and early July, with a secondary maximum in September. The rainy period of June and July is known as the *Bai-u* or "Plum rains"; it is very important for the rice crop, but the weather is most unpleasant, with very humid air, rain nearly every day and no sun. During this period leather and cloth go mouldy and stores deteriorate rapidly.

Typhoons may traverse Formosa and the Japanese Islands in almost any month, but are only a serious threat from August to October, especially in September. The winds exceed gale force, but are not so strong as the typhoon winds of South China; on the other hand they bring torrential rain. In southern Japan a fall of 35·5 inches has been recorded in twenty-four hours, of which 9·5 inches fell in two hours. In northern Formosa a fall of 40 inches has been recorded in twenty-four hours.

In spite of these disadvantages the climate of Japan is not unfavourable to Europeans, especially in the north, which is the most bracing. Even in the south the enervating effect of the hot moist summers is largely counterbalanced by the cold winters. Judged by the industry and productiveness of the Japanese the climate seems to be healthy enough to favour a considerable output of energy.

## MONSOON AND SUMMER RAINFALL CLIMATES OF AFRICA

The monsoons of Africa are less well developed than those of Asia, but in the west and south there is a clear distinction between the dry and rainy seasons. Owing to lower latitudes and smaller land mass the dry season is not cold.

WEST AFRICA (Appendix I—*French West Africa*, Dakar, Niamey; *Gambia*, Bathurst; *Sierra Leone*, Freetown; *Gold Coast*, Accra; *Nigeria*, Kaduna, Lagos; *Cameroons*, Duala).

The monsoon area of West Africa extends from about 14°–4° N. The coastal regions are hot, moist, enervating and unhealthy; the mean annual temperature exceeds 80° F. from Sierra Leone to Lagos. The more elevated and drier regions of the interior are healthier and more invigorating. The health of whites has improved in recent years, however, even on the coast, owing to improvements in habits and sanitation, and West Africa no longer deserves the title of "The White Man's Grave."

North of about 8° N. the year is divided into two seasons, the cool dry season from about November to April, with dust-laden east or north-east winds, and the warm rainy season from about May to October with south-west winds; in the north (*e.g.* Bathurst) the rainy season is shorter and more definite and the dry season is rainless. South of 7° N. the dry season is less definite; the rainy season is longer and is split into two parts by a short spell of less rain in August, which includes some bright clear days. Here the hottest month is March, before the beginning of the rains. South of about 6° N., however, this short dry season tends to disappear again, and Duala in 4° N. has only a single maximum in July. Between 4° N. and the Equator there is an almost complete reversal, July being the driest month.

The rainfall is generally heavy on the coast, the wettest stretches being from 10° N. to Cape Palmas and the north-east corner of the Gulf of Guinea; on the Cameroon Mountains the rainfall of 369 inches is almost as heavy as anywhere else in the world. The Gold Coast is exceptionally dry for its situation. The amounts decrease inland, rapidly from south to north, more slowly from west to east, the country gradually becoming more arid until it passes into the desert of the Sahara. North of about 15° N. the average is less than 20 inches a year, which is insufficient. The following table (inches) illustrates the peculiarities:—

TABLE 17.—Rainfall of West Africa

| | Lat. ° N. | Jan. | Feb. | Mar. | April | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Dakar | 14½ | — | — | — | — | — | 0·7 | 3·5 | *9·6* | 5·4 | 1·6 | 0·1 | 0·3 |
| Bathurst | 13½ | — | — | — | — | 0·2 | 3·0 | 10·9 | *19·6* | 10·0 | 3·7 | 0·2 | 0·1 |
| Freetown | 8½ | 0·3 | 0·2 | 1·1 | 2·8 | 8·6 | 18·2 | *35·5* | 32·7 | 25·9 | 10·8 | 5·6 | 1·0 |
| Porto Novo | 6½ | 0·9 | 1·2 | 3·7 | 4·9 | 8·2 | *12·7* | 4·6 | 1·2 | 4·4 | *7·1* | 3·4 | 0·6 |
| Lagos | 6½ | 1·1 | 1·8 | 4·0 | 5·9 | 10·6 | *18·1* | 11·0 | 2·5 | 5·5 | *8·1* | 2·7 | 1·0 |
| Accra | 5½ | 0·6 | 1·2 | 2·0 | 3·4 | 5·3 | *7·0* | 1·6 | 0·6 | 1·3 | *2·3* | 1·4 | 0·9 |
| Calabar | 5 | 2·1 | 2·7 | 6·4 | 7·9 | 11·9 | 15·7 | *16·9* | 16·2 | *16·3* | 12·8 | 7·5 | 2·1 |
| Duala | 4 | 1·8 | 3·7 | 8·0 | 9·1 | 11·8 | 21·2 | *29·2* | 27·3 | 20·9 | 16·9 | 6·1 | 2·5 |
| St. Thomas Is. | 0 | 4·1 | 4·3 | *7·0* | 5·6 | 4·7 | 0·5 | — | 0·4 | 0·9 | 4·3 | *5·7* | 3·6 |
| Bolobo | 2° S. | 5·0 | 7·0 | 4·6 | *7·2* | 5·6 | 0·4 | — | 2·7 | 3·8 | 6·5 | 9·6 | *10·2* |

The dry season is generally healthy. A cool dry east or north-east wind blows from the interior, known as the *harmattan* or locally as "the doctor," which in January extends to the coast at Lagos and Accra. It carries large quantities of fine dust which penetrates all crevices. On the coast there are strong land and sea breezes. In April and May the West African "tornadoes" occur, but these are not true tornadoes, merely thunderstorm squalls which occasionally unroof buildings or uproot trees. During the rainy season the winds are light; the end of this season is the most unhealthy time of year.

NORTH-EAST AFRICA (Appendix I—*Egypt*, Alexandria, Cairo; *Soudan*, Khartoum, Mongalla; *Abyssinia*, Addis Ababa; *Red Sea*, Kamaran Islands).

Climatically Egypt forms part of the Sahara-Arabia desert, but its whole life is based on the annual Nile flood, which results from the monsoon rainfall over Abyssinia. Between Cairo and Atbara (17°45′ N.) the annual rainfall is less than an inch and several years may pass without a shower. The sky is almost cloudless, the air is very dry and dusty, and the day temperatures are very high. The highest temperatures to be expected on the hottest day of the average month (*i.e.* the mean monthly maxima), the highest recorded and the average relative humidity, are as follows:—

TABLE 18.—Climate of North-east Africa

| | Jan. | Feb. | Mar. | April | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Cairo* | | | | | | | | | | | | |
| Mean Max. ° F. | 74 | 81 | 91 | 100 | 104 | 106 | 103 | 101 | 97 | 96 | 89 | 79 |
| Abs. Max. ° F. | 80 | 92 | 99 | 109 | 111 | 109 | 108 | 106 | 106 | 100 | 97 | 82 |
| Rel. Hum. % | 59 | 51 | 46 | 41 | 38 | 41 | 47 | 51 | 54 | 53 | 56 | 59 |
| *Khartoum* | | | | | | | | | | | | |
| Mean Max. ° F. | 99 | 105 | 109 | 112 | 114 | 112 | 109 | 105 | 108 | 108 | 103 | 99 |
| Abs. Max. ° F. | 103 | 109 | 112 | 115 | 116 | 115 | 117 | 109 | 111 | 109 | 106 | 104 |
| Rel. Hum. % | 26 | 20 | 14 | 13 | 18 | 28 | 43 | 52 | 42 | 29 | 25 | 27 |

With the highest temperatures the humidity may fall to 2 per cent. and evaporation is very rapid. The nights are relatively cool, and the climate is not unhealthy. For the effect of the high temperatures see Chapters VII and VIII. On the Red Sea coast the days are almost as hot, but the air is moister and the nights less cool, making the climate very unpleasant.

The worst feature of Egypt is the *khamsin*, a hot dry southerly

wind which carries great quantities of dust and is sometimes accompanied by sand- and dust-storms. The khamsin is most frequent in spring. In the Soudan strong squally dust-bearing winds are known as *haboobs*. At Khartoum more than twenty haboobs occur each year between January and October; they are most frequent in June and July. They occur most often between 2 p.m. and 10 p.m. and last about three hours.

The rainfall increases rapidly south of Khartoum, and the rainy season lengthens. At Khartoum (15½° N.) 5·2 inches fall, almost all in July, August and September. At Malakal (9½° N.) the total is 34·8 inches, from late April to early November. The heaviest rain, however, falls on the mountain plateau of Abyssinia during the south-west monsoon, and averages nearly 50 inches a year. About half the annual total comes in July, August and September, but there is a little rain even in winter. This heavy fall runs off into the Blue Nile, and though about half of the water is lost by evaporation in the Sudd swamps, the remainder causes the annual Nile flood. From Khartoum northwards practically all cultivation depends on irrigation from the river or from irrigation canals fed by the river. The flood is very variable from year to year and dams have been built at intervals to store the water from good years and to regulate the flow. A comprehensive plan for further works, involving also the Soudan, which will double the irrigable area and also provide a supply of hydro-electricity, has been prepared for the Ministry of Public Works, Egypt, by H. E. Hurst (1946) and his colleagues, and is now being put into operation.

MADAGASCAR (Appendix I—Tamatave, Tananarive).

Three climatic zones may be distinguished in Madagascar, the east coast, the central highlands and the west coast. The east coast (table for Tamatave) has a moderate temperature, with rain throughout the year, the only approach to a dry season occurring in September to November. The winds blow off the sea throughout the year, keeping the climate fresh and healthy. The central highlands (table for Tananarive) have also a moderate temperature, and in spite of the elevation the rainfall is not large. There is a well-marked winter dry season from April to October, but the humidity remains high. A peculiarity of the first part of the dry season is a kind of Scotch mist, very cold and wetting, but giving only small amounts of

rainfall. Snow is unknown, but frost is occasionally seen. During the rainy season heavy westerly squalls occur with thunder and violent rain. Temperatures do not exceed 95° in the highlands.

The west coast is much hotter and drier than the east, the average annual temperature being 79° at Mojanga (16° S.). The rainfall decreases from north to south, averaging 62 inches at Mojanga, but only 14 inches at Nossi-Be (23½° S.). The south-west coast is almost a desert, but is healthy.

The cyclones of the Southern Indian Ocean occasionally cross the island, especially the northern half; they are limited to December to April and are most frequent in February.

SOUTH AFRICA (Appendix I—*Rhodesia*, Salisbury; *Union of South Africa*, Cape Town, Durban, East London, Johannesburg, Kimberley; *South-west Africa*, Walvis Bay, Windhuk).

Almost the whole of the continent of Africa south of 10° S. is occupied by an extensive plateau, between 3,000 and 6,000 feet high, rising in the Drakensberg to nearly 12,000 feet. The low ground forms only a very narrow fringe round the coast in the west and south, but broadens out in the east. The result of this topography is a great uniformity of climate over a large area, while the temperature is low for the latitude and resembles that of western Europe. Since the highest elevations are rather near the coast, rainfall over the interior is generally deficient. On the edge of the plateau where the air descends rapidly to the coastal plain, "hot winds" occur, similar to the Föhn and Chinook. These *berg winds* are most frequent on the south coast, where they blow on twenty to thirty days a year, mostly in winter, when they cause very high temperatures, often exceeding those of summer. When they blow for two or three days they are very oppressive. On 22nd January 1923 a temperature of 118° F. was recorded at Dunbrody in the south of the Cape Province during a berg wind; mealies and other crops were destroyed and some cattle, ostriches, fowls and bees died.

Dust-storms are frequent, especially from August to December. The fine dust is raised by a strong, squally wind and is very penetrating, but the dust-storms rarely last long and are usually followed by rain.

The climate is extreme; maximum temperatures exceeding 100° F. have been recorded over most of the area, except at high-level towns such as Johannesburg, and all over the plateau 95° is exceeded in most years. The minima are correspondingly

low in the interior, and temperatures below 32° F. have occurred as far north as Salisbury. The coasts are less extreme and even the south coast is mostly free from frost. Relative humidity is moderate on the south and east coasts, but low in the interior, averaging only 54 per cent. at Kimberley. In spite of its desert character the west coast has a cold, damp and very foggy climate with, however, very little rain.

The annual variation of rainfall shows a maximum in summer and a minimum in winter over most of the area. Winter is very dry in Northern Rhodesia and Nyasaland, and in the interior of South Africa, especially Matabeleland, Damaraland and Great Namaqualand, and to a less extent in the Transvaal. The provinces of the east coast, Mozambique, Lourenco Marques, Zululand and Natal, have an appreciable winter rainfall. Here, in addition to the usual summer thunderstorms, rain is brought by gales from the sea, which may come at any season. In Natal these are known as "three-day rains" because they generally last two or three days. In summer cyclones from the Indian Ocean sometimes approach the coast of Natal and bring heavy rain. The following table of monthly rainfall in inches summarises the annual variation:—

TABLE 19.—Rainfall of South Africa

| | Jan. | Feb. | Mar. | April | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mozambique and Natal | *5·8* | 5·0 | 4·8 | 2·8 | 1·6 | 0·9 | 0·6 | 1·1 | 1·4 | 2·7 | 3·9 | 4·7 |
| Transvaal | *6·1* | 5·3 | 4·1 | 1·5 | 0·4 | 0·1 | 0·1 | 0·3 | 0·8 | 2·0 | 3·9 | 4·8 |
| South Coast | 1·8 | 2·1 | *2·4* | 2·3 | 2·3 | 1·9 | 1·6 | 2·2 | 2·6 | *2·7* | 2·3 | 2·3 |
| South West Cape Province and Cape Peninsula | 1·1 | 0·7 | 1·2 | 2·8 | 4·6 | *5·2* | 4·2 | 4·2 | 3·0 | 2·6 | 1·3 | 1·2 |

Over the interior a large part of the rain falls in severe thunderstorms which occur on more than thirty days a year over most of the Transvaal, Basutoland and eastern Cape Province. Hail is remarkably frequent, occurring on 105 days a year in the Cape Province and Transvaal, mostly in summer. In the most severe storms some of the hailstones may be as big as cricket balls and weigh up to 1½ lb.; they kill sheep and cows and pierce corrugated iron roofs like paper. Fortunately they are not usually accompanied by wind, though one violent hailstorm was preceded by a true tornado of the American type. Some heavy falls of rain have been recorded in thunderstorms, including one of 16·5 inches at Swellendam.

In the west of South Africa thunder is rare. The west coastal region of South-west Africa is true desert and uninhabited.

South Africa is noted for its sunshine. This and the dry air, especially of the central and upper Karoo, make it very suitable for sufferers from tuberculosis and phthisis. In the Orange Free State and Transvaal cold wet weather is unknown, but the dust is liable to cause ophthalmia.

NORTHERN AUSTRALIA (Appendix I—Darwin, Thursday Islands).

The northern coast of Australia lies well within the tropics, and has a typical monsoon climate. The north-west monsoon blows from December to March; in West Australia it becomes south-westerly and is cooler and drier. The south-east trade wind blows for the rest of the year. Owing to the warm seas to the north the climate is warm throughout the year, and is especially oppressive in April. The dry season from May to October has only a few showers; the rainy season comes in almost suddenly in December and torrential rain falls almost every day for three or four months. Inland the rainfall decreases rapidly, especially in the west, and soon passes into the desert. For the monthly and annual rainfall see p. 114 and Fig. 13.

MEXICO AND CENTRAL AMERICA (Appendix I—*Mexico*, Mazatlan, Mexico City, Salina Cruz, Vera Cruz; *British Honduras*, Belize; *Costa Rica*, San José; *Guatemala*, Guatemala; *Panama*, Balbas Heights, Cristobal; *San Salvador*, San Salvador).

Mexico is a land of varied climates, from the hot, steamy southern shore of the Gulf of Mexico to the north-western deserts. A large part of the country consists of a lofty plateau over 6,000 feet above sea level. The inhabitants divide the country into three zones, the *tierra caliente* (hot lands) up to 2,000 feet, the *tierra templada* or moderate zone from 2,000 to 6,000 feet, and the *tierra fria* (cool land) above 6,000 feet, but even the latter has, over most of its extent, a hot summer climate. At Mexico City, 7,500 feet up, the mean temperature exceeds 60° F. from March to September. In addition, there is a marked difference between the rainy eastern and dry western sides. The rainfall varies from over 100 inches on the slopes facing eastwards above the southern parts of the Gulf of Mexico, around Vera Cruz, to less than 20 inches over most of the interior plateau and less than 10 inches in Sonora and Lower

California. On the southern Pacific coasts it increases again, amounting to 40 inches a year at Salina Cruz in Oaxaca. On the plateau water is scarce and has to be drawn from wells which may be as much as 100 feet deep.

Over most of Mexico there are three seasons, the "cold weather" from November or December to February, the "hot weather" from March to May, the two together forming the dry season or *verano*, and the rainy season from June to October. In the south the rain is less heavy in July and August than in June and September, forming the lesser dry season or *veranillo*. On the Atlantic side this is barely perceptible, but on the Pacific side it brings a real break, with dry weather and a rise of temperature. At Salina Cruz the monthly rainfalls and daily maximum temperatures are as follows:—

| | Jan. | Feb. | Mar. | April | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Rainfall, inches | 0·2 | — | — | 0·3 | 3·0 | *14·6* | 2·4 | 3·8 | *10·2* | 5·4 | 0·3 | 0·1 |
| Mean daily max. temp. °F. | 83 | 84 | 85 | 87 | *88* | 85 | 88 | *89* | 86 | 85 | 85 | 84 |

The "cold weather" is dry and sunny over most of the country. The prevailing winds blow from east or ENE.; they are steady and stable and bring rain only on high ground facing the Gulf of Mexico. They are interrupted from time to time, especially in January and February, by cool northerly winds or *Nortes*, the continuation of the Northers of the United States. These are strong and stormy on the southern Gulf Coast, and bring persistent fine rains. On the western shores of the Gulf they are stormy and distinctly cold, and in the lee of the mountains they are cold and dry, and bring frosts; sometimes they descend the Pacific slopes as the hot dry dusty *papagayo*. The Gulf of Tehuantepec suffers in winter from the *Tehuantepecer*, a violent north wind which is a continuation of the cold waves from North America, blowing through the 70-mile wide gap in the Cordilleras in the Isthmus of Tehuantepec.

In March, April and May the wind becomes more southeasterly and cloudiness begins to increase, but is not enough to balance the increasing heat of the sun; the days are very hot, but the nights are cool. On the humid Atlantic lowlands whites cannot work in the open at noon and in the afternoon. The day temperatures at this season are even higher on the Pacific

coast, but the air is so dry that the evaporation of perspiration cools the body and the heat is not felt to the same extent.

During the rainy season winds blow in towards the central plateau from all sides. The rain falls mainly in thunderstorms, which occur almost every day. At the beginning and end of the rainy season violent thundery squalls (*chubascos*) are experienced. Rainfall is heavy on the coasts, moderate on the interior plateau and very light in the north-west. The skies are cloudy and the nights warm and humid. This is the least healthy season.

The Atlantic coast of Central America has a hot rainy and humid climate, the annual rainfall exceeding 120 inches with rain in all months. The rain comes mainly in steady falls of long duration and wide extent, especially in the winter. In the valleys of the interior the rainfall is about 60 inches and comes almost entirely in summer, in the form of heavy thunder showers. Finally the rainfall increases again towards the Pacific coast and averages about 80 inches, though it still falls almost entirely in summer and mainly in thunderstorms.

WEST INDIES AND BERMUDA (Appendix I—Nassau (Bahamas); Barbados; Havana (Cuba); Port-au-Prince (Haiti); Kingston (Jamaica); Fort-de-France (Martinique); San Juan (Porto Rico); Port of Spain (Trinidad); Bermuda).

The West Indies have a definitely tropical climate, the mean annual temperature being everywhere between 75 and 80° F. The Bahamas and Cuba come to a considerable extent under the continental influence of North America; the large islands of Cuba and Hispaniola are also large enough to have moderately continental climates of their own. Port-au-Prince, on the leeward side of Hispaniola, has even recorded a maximum temperature of 101° F., while San Domingo, in the north-west of the same island has never exceeded 95° F. Southward and eastward the climate becomes more oceanic and the small islands of the Leeward and Windward groups (Lesser Antilles) are entirely dominated by the Trade Winds, and are very equable. At Barbadoes, for example, the difference between the warmest months (July to September) and the coolest month (February) is less than 4° F. compared with 11° F. at Havana (Cuba) and Nassau (Bahamas). Trinidad and Curaçao are climatically parts of South America. In winter the Bahamas and Cuba occasionally have minima below 55° F. when cold waves from the U.S.A. succeed in crossing the ocean. The

lowest recorded temperatures are (° F.): Havana, 50; Nassau, 51; Kingston, Jamaica, 57; Montserrat, 59; St. Lucia, 60; Grenada, 60.

In the Lesser Antilles the trade winds blow strongly and very steadily from east throughout the year. Farther west they are weaker, but are steady over the open sea. On the larger islands sea breezes develop on the lee sides, especially in the dry season, and on the weather sides the trade wind drops to calm at night or is even replaced by a light breeze off the land. Except in southern groups off the north coast of South America the winds also fall light when a storm is passing to the north.

The rainfall is everywhere considerable; owing to its importance for the sugar industry rain-gauges are very numerous. The annual totals vary greatly according to the exposure; on windward slopes they are two, three or more times the fall on leeward slopes. In Jamaica, for example, Kingston in the lee of the high Blue Mountains has a rainfall of only 31·5 inches compared with 137 inches at Port Antonio on the windward side. There is a double rainfall season, with maxima in May and October, retarded in the southernmost islands south of about 15° N. to June and November. The driest months are February and March, but on windward coasts rain falls throughout the year. On the leeward sides of large islands there are thunderstorms with heavy rain in April and May. Heavy rains also fall when unusually strong winds blow on steep slopes facing the sea. On Silver Hill, Jamaica, no less than 135 inches fell during 4th–11th November 1909, 30·5 inches in one day. Hurricanes are accompanied by torrential rain; in Porto Rico 11 inches fell in a few hours in August 1899. The floods which followed the hurricane of 10th–13th September 1898 in St. Vincent swept away whole villages. The same happened in Jamaica in November 1912.

Hurricanes can occur in almost any month, but are very rare from December to May. They are most frequent between August and October. From 1887 to 1923 239 were recorded, an average of between six and seven a year, distributed as follows:—

| Jan.–April | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|
| — | 1 | 16 | 17 | 39 | 78 | 71 | 15 | 2 |

They usually originate to the east of the Lesser Antilles and travel west-south-west at first, usually turning north-east somewhere

in the West Indian area. The belt of greatest frequency runs across Haiti, Cuba and the Bahamas; Trinidad is almost outside the hurricane area. The wind speed often exceeds 100 m.p.h.; in fact, a speed of 130 m.p.h. has been recorded on several occasions, and in the storm which destroyed Santo Domingo on 3rd September 1930 the speed was estimated from the damage as 160 m.p.h. This storm caused many thousands of deaths.

Hurricanes do great damage to crops and buildings, but thanks to the efficient warning system of the U.S. Weather Bureau the loss of life is generally small. The damage is due not only to the winds; "hurricane waves" flood low-lying ground and wash away houses.

Bermuda has an oceanic sub-tropical climate, but, lying well to the north of the West Indies, is cooler and less tropical. Owing to the absence of the invigorating trades it is also more enervating, especially when the south wind is blowing. The winter is moderately cool, a minimum temperature of 40° F. having been recorded, and even snow is experienced very occasionally. uly to October are very sultry months, with hot, oppressive nights like a steam bath. The climate is much less healthy than that of the Bahamas. Hurricanes sometimes pass over the islands.

The smaller West Indian islands are largely built of porous rock, such as coral limestone, and there is no surface water, the supply being drawn mainly from wells. In Yucatan, which has a similar structure and is similarly situated, the water is pumped up by windmills driven by the steady trade winds, and there is probably scope for a considerable extension of this practice in the West Indies.

## SOUTHERN SOUTH AMERICA

South America extends from north of the Equator into high southern latitudes. Brazil and the northern countries are best considered under the head of tropical climates (Chapter VI), but most of Chile and the Argentine are sub-tropical or temperate. As in North America the continent is divided longitudinally by a high mountain range, the Andes, into two parts with very different climates.

THE ARGENTINE, PARAGUAY, URUGUAY (Appendix I—*Argentine*,

Buenos Aires, Cordoba; *Paraguay*, Asuncion; *Uruguay*, Montevideo).

Owing to the shelter of the Andes the eastern part of southern South America has a rather continental climate, with considerable annual and diurnal ranges of temperature, and in general a moderate or scanty rainfall. It may be divided into a sub-tropical section from 21°–40° S., and the inhospitable Patagonian region south of 40° S., described in Chapter IV.

The wide plains (Pampas) north of 40° S. and east of 65° W. have a rainfall of 20–40 inches, increasing to over 80 inches locally in the north-east corner. Near the coast the rainfall is fairly well distributed through the year, with a maximum generally in summer and autumn and a minimum in winter, but there is a second minimum at midsummer. Farther west the seasonal contrast increases, and west of 62° W. the winters are almost dry. The weather throughout the year is made up of an alternation of cool dry southerly and south-westerly winds and warm moist northerly winds. The latter, coming from low latitudes, are sultry and enervating. The southerly winds generally set in suddenly, bringing the temperature down by about 12° F. In spring and early summer they are often stormy, when they are known as "Pamperos"; these occur three or four times a month from October to January. They sweep over the plains, heralded by dust-clouds and bringing local heavy showers, which are welcome in summer. On the coast dangerous south-easterly gales blow up two or three times a year. "Buenos Aires" is rather a misnomer for the city; Don Pedro de Mendoza, who named it, happened to arrive on one of the rare calm days. It is hot in summer and humid in winter, but on the whole it is healthy and very fertile.

Inland the rainfall decreases and agriculture becomes precarious. The dry summers are interrupted at intervals by sudden downpours which flood the ground; changes of temperature are large and rapid, and night frosts are frequent. At San Luis, in 33° S., the recorded extremes of temperature are 102° and 19° F. Hail is also frequent and plagues of locusts are an additional trouble. Along the eastern margin of the Andes is a narrow belt of semi-arid country, with few settlements, which widens southwards into Patagonia.

NORTHERN AND CENTRAL CHILE (Appendix I—north to south, Arica, Antofagasta, Valparaiso, Santiago).

The long narrow coastal strip west of the Andes has an extraordinary diversity of climate. Northern Chile is completely rainless; the average annual fall is less than an inch as far south as 29½°, and a year or two may pass without a drop. The rainless regions are watered by melting snow from the mountains, and the settlements strung along the rivers are famous for their dried fruit. The coast is almost uninhabited, and the road and railway run along the inland side of the desert. Between 29½° and 32° S. a few short, heavy showers fall each year. In 32° S. the average is 5 inches, and southward the amount increases rapidly to 10 inches in 33°, 20 in 34°, 30 in 35°, 40 in 37°, 60 in 38° and 80 in 39° S.

In the interior of Chile the rainfall is generally greater than on the coast, but the amount is everywhere less than 10 inches as far as 30° S. From about 32° to 42° three zones can be distinguished, a coastal zone; the valleys between the coastal mountains, which are drier than the coast; and the main ridge of the Andes, with a relatively high rainfall and a good deal of thunder. Between about 35° and 38° S. there are long periods of heavy rain ("temporales") which flood the river banks and do much damage to the crops along the valleys. In central Chile the rain is limited to the winter months; in 30° S. summer is almost rainless, but southwards the summer rainfall increases and in 50° S. the amounts are almost uniform throughout the year.

The prevailing winds are from south-west in the north and from west in the south, very stormy south of 40° S. (the "roaring forties"). North of 40° there are strong land and sea breezes blowing up the mountains by day and down them by night, and these keep the summer temperatures moderate.

The climate of Santiago in 33½° S. is favourable, with calm, mild sunny winters and cool dry summers, so that the gardens are very rich. There is an "Indian Summer" of fine warm hazy weather at the end of March or beginning of April. The northern part of Chile is subject to earthquakes. These are generally submarine, and cause great sea waves along the whole coast. The mountain climate of the high Andes is discussed in Chapter VII.

## CHAPTER VI

# TROPICAL CLIMATES

MOST of the equatorial regions have a hot, humid and rainy climate throughout the year, with very little difference between the warmest and coolest months. Thunderstorms are frequent and severe, but the equatorial regions are almost free from major climatic catastrophes such as hurricanes and tornadoes. Moreover, the heat, though steady, is never extreme; over much of the equatorial zone the temperature never reaches 100° F. and rarely falls below 60° F. at moderate altitudes. The heat and humidity are very enervating, and the absence of a cool season allows no period of recuperation; hence whites need a periodical return to a cooler climate. Without careful hygiene tropical diseases are rife, and vegetation grows so rapidly that it is difficult to cope with. Metals corrode, cloth, paper and leather go mouldy. The equatorial regions are unsuitable for factory work, but are valuable sources of raw material. The only equatorial regions which are suitable for permanent occupation by whites are the highlands.

There is still some controversy about the effect of tropical climates on the health of white settlers and officials, some writers believing that with proper care the tropics are as healthy as any other part of the world, and others that they are quite unsuitable for white colonisation. The truth probably lies between the two extremes. The death-rate where known is found to be little if any higher than in temperate countries, but this is readily accounted for by the facts that whites going to live in the tropics are initially sound and healthy, that they live under more comfortable conditions than the bulk of the population in the mother country, and that many of the older settlers and officials return home on retirement. Even under these favourable conditions the sickness rate is high. Sir Aldo Castellani (1938) quotes figures for Kenya, which is among the healthiest of the equatorial countries because of its elevation, showing that in 1938, out of 1,717 resident officials, 1,462 had some period of sickness during the year, though the average

duration was only a week. In the tropics one tends to surrender easily to the first symptoms of disease. The main cause of both sickness and death is malaria; there is also a remarkably high incidence of appendicitis, which may be due to unusual kinds of food. A minor trouble, which also appears during heat waves in temperate regions, is slight swelling of arms and legs (heat œdema). Anyone going to the tropics should prepare for this by taking larger shoes, but apart from some discomfort there are no ill effects.

On the coast in tropical countries land and sea breezes are well developed during dry periods. The sea breeze coming in during the hottest part of the day brings cooler air and welcome relief. The land breeze which sets in suddenly in the evening or at night is also cool; whites who have been long on the coast and whose vitality has been lowered even find it cold and dread it because it causes chills. The body loses some of its power of rapid adjustment to changes of temperature and is especially liable to chilling by wind.

The equatorial climate is found *in excelsis* in the great rain forests of the Congo and the Amazon valley. In East Africa, Ceylon and the East Indies the climate is intermediate between the rain forest and monsoon types.

THE CONGO BASIN AND NEIGHBOURING PARTS OF WEST AFRICA (Appendix I—*Belgian Congo*, Eala, Elizabethville, Leopoldsville, Angola, Loanda, Mossamedes; *French Equatorial Africa*, Libreville).

The Congo Basin has a uniformly hot, humid climate. The highest temperatures come about the time when the sun is overhead at noon, but are never extreme. The cloud cover and the forest make the region a perpetual hot-house, very enervating to whites. The country may be divided into five regions:

(1) North of about 2° N. there is a short "dry" season from December to February, but although there is little rain the air remains humid and clammy, and a thick, wet mist (*cacimbo* or "smokes") forms evening and morning. In the far interior, where the forests give place to grassland, the natives burn the grass during the dry season, and the smoke makes the air very hazy and dirty. Immediately after sunset during the dry season, over the whole basin, a strong squally wind springs up from west, often carrying dust, and reaches a velocity of 20–25 m.p.h. In the rainy season, which extends from April to

October with a short break in July, morning and evening are generally bright and clear. The dry season is most favourable for newcomers, but after some years settlers prefer the rainy season.

(2) Near the Equator there is rain throughout the year, mostly in the afternoon, and no differentiation into seasons. The interior upland is not unhealthy, but the swamps of the lower river are fever-ridden, especially near Boma.

(3) South of about 3° S. the climate is similar to that of the northern region, but with the dry season from June to August or September.

(4) In the extreme south (Katanga, 10° S., 26° E.) is a drier and healthier plateau climate.

(5) Along the coast regular land and sea breezes bring welcome relief from the heat. Over the whole region thunderstorms are very frequent and "tornadoes" similar to those of West Africa also occur.

EAST AFRICA (Appendix I—*Kenya*, Mombasa, Nairobi; *Nyasaland*, Zomba; *Tanganyika*, Daressalam; *Uganda*, Entebbe; *Zanzibar*).

Owing to the rugged topography and great range of elevation the climates of East Africa are very varied. The north coastal plain north of about 7° S., about 100 miles wide, has a hot climate which is relieved by the large diurnal range of temperature and humidity. The rainfall is not excessive (40–50 inches a year on the mainland, about 70 inches on the islands of Zanzibar and Pemba). The worst times are from December to March, when the air is uniformly hot, and the period of heavy rain in April and May. The pleasantest time is from the end of June to mid-September.

Tanganyika and Nyasaland have a much longer but less intense rainy season from November or December to April; it is only near the northern end of Lake Nyasa that the rainfall is heavy. Central Tanganyika east of Tabora is semi-desert.

Kenya has two rainy seasons, about November and from April to June; the latter are known as the "long rains" and make travel difficult. From December to March the days are hot and sunny, but with some heavy afternoon showers. July to September are cool, sunny and dry, sometimes rainless; on the highlands the nights are cold and dense mists occur in the mornings.

The lake region of Uganda has plentiful rainfall, especially on the northern shores of Lake Victoria. The rainfall is well distributed through the year, but afternoon rains are especially heavy in April to May and August to October. Vegetation is very rich near the lake; farther from the shores the rainfall decreases.

Northern Kenya and north-eastern Uganda are hot and arid, with a rainfall of less than 20 inches a year which falls mainly in short, violent thunderstorms. These regions are of little economic value and almost uninhabited.

Those parts of East Africa which have sufficient rainfall are very rich agricultural regions, and the plateau is cool enough for permanent settling by whites. Where in a normal year the rainfall is barely sufficient, severe droughts sometimes occur, and there is a risk here that clearing the bush may alter the character of the rains, making them more violent and spasmodic and so of less value, and allowing the rain-water to run to waste more readily.

THE NORTHERN HALF OF SOUTH AMERICA (Appendix I—*Bolivia*, Sucre; *Brazil*, Manaos, Para, Pernambuco, Rio de Janeiro; *Guiana*, Georgetown; *Columbia*, Bogota; *Ecuador*, Guyaquil; *Peru*, Lima; *Venezuela*, Caracas).

The climate of Central America and northern South America east of the Andes is mostly typically equatorial, with high but not excessive temperatures, a small annual range and high humidity. The climate of most regions is enervating and the equatorial parts tend to be unhealthy, especially in the lower Amazon valley; the drier and more elevated regions are healthier. Health is largely a matter of hygiene and drainage; The Panama Canal Zone, for example, was formerly deadly, but is now healthy. Cayenne is said to be very unhealthy, but this cannot be due entirely to the climate, as Georgetown (British Guiana) has a similar climate, but a much better reputation. The rainfall is heavy over most of the area, but there are "islands" of drought, such as those of Ceara and Maracaibo, where agriculture is precarious. Southern Brazil extends into the region of sub-tropical climate, with cool invigorating winters. On the north and east coasts the trade winds blow freshly throughout the year, but in the interior the winds are light. Land and sea breezes are well developed on the coast of southern Brazil; at Rio de Janeiro they blow very

regularly, the Bay being protected from the strong north and south winds. The sea breeze comes in between noon and 2 p.m. and lowers the temperature by 7–10° F., bringing relief from the heat. In summer thunderstorms frequently occur in the evening. The best time of day is the morning, when the sky is clear and the air fresh; the worst time in the interior is the afternoon, especially during the rainy season, before the afternoon rain, when the air is very oppressive.

The annual variation of rainfall differs according to locality, but as a rule the rainfall is heaviest when the winds are lightest and most irregular in direction. In Guiana and Venezuela the rainy season extends generally from May to November. In the north there is a single maximum in June and July; the dry season is very pronounced. On the llanos south of the high ground the months of December to February are rainless and in many years the first rain does not fall until May. The average relative humidity is below 60 per cent. and the sky is very clear. In the valley of the Orinoco, however, the humidity is high and the rainfall considerable in all months. In the west of Venezuela there is a double maximum; Merida receives 1·6 inches in February, 10·9 in May, 4·6 in July and 10·4 in October. A similar distribution occurs in the upper Amazon valley.

Near the coast of Guiana the maximum falls in May, when the rainfall is very heavy; about September there is little rain. The south-eastern coast of Brazil south of 20° S. has a maximum in December to March and a minimum from June to August, July being almost rainless in places. The coastal plain near Pernambuco, on the other hand, has a maximum in June and July and a minimum in October to December. The rain comes in steady falls of long duration, rather than in the usual tropical showers, and thunder is rare, but the amount is very variable from year to year.

In southern Brazil, between latitudes 15° and 22° on the coast and farther south in the interior there is a definite maximum in December to March and an almost rainless winter, but south of 22° on the coast, including Rio de Janeiro, there is little annual variation.

Thunder is frequent over most of tropical South America east of the Andes, exceeding 100 days a year in the south of Matto Grosso and part of the Amazon estuary. The only parts in which thunder occurs on less than thirty days a year are

British Guiana, the middle Amazon valley and the north-eastern corner of Brazil, where the coast from Cape San Roque almost to Bahia is almost free of thunder.

West of the Andes the rainfall is very heavy (exceeding 200 inches) at the foot of the mountains near the Equator, but decreases rapidly southwards; the coast of Peru is almost rainless (less than 2 inches). The temperature on the coast is low for the latitude, increasing inland even at moderate elevations.

EAST INDIES, MALAYA AND PACIFIC ISLANDS (Appendix I—*Borneo*, Sandakan; *Celebes*, Menado; *Java*, Batavia; *Malaya*, Singapore; *Philippines*, Manila, Surigao; *Sumatra*, Medan, Padang; *Timor*, Keopang; *Caroline Islands*, Yap; *Fiji Islands*, Suva; *Hawaii*, Honolulu; *New Caledonia*, Noumea; *Samoa*, Apia; *Solomon Islands*, Tulagi; *Tahiti*, Papeete).

The climate of the island regions of south-eastern Asia and the Pacific is characterised by uniform heat, high humidity and abundant rainfall, except in the lee of mountain ranges where dry winds occur, such as the *bohorok* of eastern Sumatra during the west monsoon. North of the Equator the winds are north-easterly from November to March and south-westerly from May to October. In the East Indies south of the Equator they are north-westerly (the "west monsoon") from November to March and south-easterly (the "east monsoon") from May to October. In the transition periods the winds are generally light and, on the coasts of the larger islands, are dominated by land and sea breezes. On the small Pacific islands west of about 150° E. the trade winds blow throughout the year.

There is not much annual variation of temperature; in the north the hottest period is between June and August and the coolest January and February. In the south the hottest months are January to March and the coolest July and August. Near the Equator there are two maxima, about May and October. Excessive temperatures are found only in the interior of the larger islands, especially in the Philippines, where a range from 112°–54° F. has been recorded at Tugueguaro in Luzon.

The rainfall is heavy and falls mostly in thunderstorms, which are very numerous and severe, the average frequency reaching 322 days a year at Buitenzorg in Java. Near the Equator rain falls almost uniformly through the year, but farther north and south, in the mountainous islands, there are marked wet and dry seasons. The rains fall when the wind is

onshore; in the north the eastern sides of the islands are rainy from October to February and the western sides from May to October. In the south this distribution is reversed.

The climate of small islands well exposed to the winds is pleasant and healthy, improving with distance from the Equator. Cocos-Keeling Island is said to be the healthiest place in the tropics. Sheltered places in the lowlands of large islands are enervating and rather unhealthy, but there are good mountain health resorts, such as Tosari in Java and the Cameron Highlands in Malaya.

North of 5° N. typhoons occur, especially in the Philippines, which experience four or five severe typhoons each year, mostly from July to November (maximum October). When these strike Manila or other large towns they do a great deal of damage. The extreme south-eastern islands of the East Indies are occasionally visited by cyclones between December and April. Cyclones are unknown near the Equator, but in the Malacca Straits there are violent south-west squalls with thunder and torrential rain; these occur only at night, mostly between April and October. The idyllic existence of the small Pacific Islands is only interrupted at long intervals by the passage of typhoons or cyclones. When they do strike an island, however, they are disastrous. Notable examples were the Fiji cyclones of 3rd March 1886 and 21st January 1904, in both of which the smaller islands were overwhelmed by cyclone waves, with great destruction not only of houses, but also of coconut trees, the islands' most important economic asset. On 15th March 1889 Apia, in Samoa, was struck, with the loss of a number of warships (but the cyclone may have saved a war!). Another cyclone visited Samoa, as well as the Union and Cook Islands, in December 1925. Cyclones or typhoons very rarely occur between 5° N. and S. latitude, but one wrecked Butaritari in 3° N. in the Gilbert and Ellice Islands in December 1927.

CEYLON (Appendix I—Colombo).

Ceylon has three climates, the west coast, the east coast, and the mountainous interior. The south-west and west coasts, represented by Colombo, are uniformly hot and moist. The annual rainfall is nearly 100 inches, and the mean temperature at Colombo ranges only from 84° F. in October to 88° F. in March and April; vegetation is rich. There are two main rainy seasons, from April or May to July, following the "burst" of

the south-west monsoon, and in October and November in the transition period between the south-west and north-west monsoons. The intervening period is one of fresh south-west winds with clearer skies but occasional bursts of heavy rain. The dry season comes in January and February, during the height of the north-east monsoon; but in spite of the shelter of the hills these months are not rainless.

On the east coast the rain is less heavy (about 60 inches a year), and falls mainly during the north-east monsoon between October and January; the remaining months are rather dry though not rainless, and the vegetation is much less luxuriant. The period of the north-east monsoon is comparatively cool, the mean temperature at Trincomalee on the east coast being 78° F. in December and January, and rising to 85° F. in May to July.

In the mountains the main rainy season extends from June to October, during which time the peaks are enveloped in cloud. Temperatures at a height of 6,000 feet or so are moderate (about 60° F.), and the hill stations are used as health resorts. In Colombo the favourite time for going to the hills is at the beginning of the north-east monsoon, when the "land wind" sets in, as this is regarded as the unhealthy season on the west coast.

# CHAPTER VII

## DESERT, MOUNTAIN AND POLAR CLIMATES

THIS chapter considers briefly those parts of the earth which by reason of drought, elevation or cold are inimical to man. They are of direct interest only for mineral products, furs and in a few cases as health or holiday resorts, but they may be of indirect importance as barriers to trade. Their extent is shown in Fig. 1.

DESERT CLIMATES (Appendix I—*Asia*, Urumtsi; *South America*, Antofagasta, Arica, Lima; *Africa*, Insalah, Cairo).

Desert conditions may arise on a small scale as a result of soil which is too poor for agriculture, either naturally or from overcropping and exhaustion, or because of a very porous or fissured sub-soil which allows the rain-water to sink in too rapidly. The great deserts of the world, however, are all due to a shortage of rain combined with considerable evaporation. Outside the polar regions any area with an average rainfall of less than 10 inches a year will be unproductive desert unless it can be irrigated.

The significance of deserts in the world's economy is shown by the following table of the areas of the desert parts of the various continents:—

| *Continent* | *Area of desert, square miles* | *Per cent. of continent* |
|---|---|---|
| Africa | 3,630,000 | 32 |
| Asia | 1,165,000 | 7 |
| North America | 458,000 | 5 |
| South America | 582,000 | 9 |
| Australia | 1,090,000 | 37 |

Nearly half of this great desert area is made up of the Sahara and Arabia, which extend from the Atlantic to the Indian Ocean between 15° and 30° N.

Besides lack of rainfall, the characteristics of deserts are the intense insolation, the enormous range of temperature both from night to day and from winter to summer, the low relative humidity by day and the large evaporation, and the storms of dust and sand. In the central Sahara, represented by Insalah, and in central Asia (Urumtsi), the averages of the highest and

lowest air temperatures each day, and the daily range, are as follows:—

| | Insalah | | Urumtsi | |
|---|---|---|---|---|
| | Jan. | July | Jan. | July |
| Mean Daily Max. ° F. | 69 | 117 | 31 | 94 |
| Mean Daily Min. ° F. | 40 | 82 | −21 | 50 |
| Mean Daily Range, ° F. | 29 | 35 | 52 | 44 |

The highest and lowest temperatures on record at Insalah are 133° F. and 25° F.

The highest temperatures of all are recorded in shallow depressions where the rocks reflect the sun's heat from all sides. In such a situation a shade temperature of 136° F. has been recorded at Azizia in Tripolitania—the world's highest—and 134° F. at Death Valley, California. Surfaces exposed to the sun reach much higher temperatures by day; at night they cool very quickly directly the sun has set. The surface of loose sand gets especially hot because of the insulating effect of the air between the grains; values exceeding 170° F. have been measured (see Chapter VII). Such surfaces are painful to walk on, and it has been remarked that in battles soldiers prefer to stand up and risk the bullets rather than lie down and be burnt alive. Solid rock does not get quite so hot, though a temperature of 160° F. has been recorded, but the heat penetrates farther into the rock and it cools more slowly. The interiors of tents get very hot, and summer dwellings should be very thick walled and roofed, or built underground.

The relative humidity falls to very low figures during the hottest days—values of 2 or 3 per cent. are not unusual. The drying power of the air depends on the *saturation deficit*, or the difference between the amount of water vapour actually in the air and the amount which it could hold if saturated at the same temperature (drying power also, of course, increases with increasing wind velocity). The average saturation deficit *in the shade* at midday at Insalah in July is about 64 grams per cubic metre of air, compared with only 9 grams in London. A table of saturation deficit in terms of temperature and relative humidity is given in Appendix II. At temperatures higher than those of the air in shade, such as are reached

near the surface of the sand, the saturation deficit is even greater.

In spite of the low relative humidity at midday, the daily range of temperature is so great that the air is often saturated at night and dew is formed. Moreover, the daily change in the volume of air is so great that flexible packing covers which are not hermetically sealed are soon rendered useless, and the contents are subjected to alternate drying by day and damping by night. J. Gottmann (1942) remarks that this large daily range can be utilised to abstract water from the air by constructing a pyramid of stones. A film of water spreads over the stones; as the temperature falls at night the film contracts and the surplus water collects in drops which drain away. A pyramid of broken limestone with a base 30 feet square gave a little water in winter, and in summer more than four pints a day. A similar cone constructed in the Crimea is said to have given about 80 gallons even on rainless days. The method is very old, having apparently been in use in prehistoric times (W. Midowicz, 1948).

The other main characteristic of deserts is the prevailing *dustiness* of the air. Except after the rare rainstorms the air is full of a fine haze, which penetrates all crevices. On hot afternoons there are whirling pillars of fine sand; when the wind is stronger the whole ground seems to be in motion and walking is difficult. But the worst condition is the *simoom* or "poison wind" of North Africa and Arabia, also called *chihili* or *ghibli*, which is similar to but more intense than the *khamsin* of Egypt and the *haboobs* of the Soudan. The simoom is a blast of hot air often accompanied by heavy clouds of dust or sand, which limits visibility to a few yards. The heat is intense (125° F. or more, 133° F. has been recorded) and the air seems to glow. The dust and dryness not only inflame the eyes, but also cause nervous troubles, known in Tripoli as *ghiblitis* (Castellani, 1938). The hot dry winds result in the removal of a large quantity of moisture from the body, and this has to be replaced by drinking an equivalent quantity of water. As perspiration removes salts, these must be replaced, either in the food or by slightly salting the water, or heat cramp will result. Since the evaporation of perspiration is nature's way of keeping the body temperature steady, men who do not perspire freely should keep away from all hot dry climates and especially deserts.

When the air temperature is considerably above body temperature and there is appreciable wind, the air brings more heat to the body than can be disposed of by the sweat glands, in spite of the very low relative humidity. The body temperature rises, and if the rise goes far enough, heat stroke ensues and in the worst cases leads to death (see p. 22).

The dust and sand in the air are very injurious to machinery. Very little wind is sufficient to raise fine surface sand; R. A. Bagnold (1937) states that a wind of 2·5 metres per second (5·6 m.p.h.) raises fine dune sand, the quantity transported being proportional to the cube of the wind speed above this minimum. A. Brun (1944) remarks that the passage of locomotives on railways in desert countries creates a wind which fills the air with particles up to a diameter of 100 microns (equal to one-tenth of a millimetre). The filter system for ventilating locomotives should exclude all particles larger than 50 microns, and that of the air admitted to the cylinders all larger than 10 microns, to keep the lubricating oil clean. Ventilation of passenger coaches also presents difficulty; the best plan is to exclude the outside air altogether, and ventilate by air-conditioning and fans. The sand frets away paintwork, and a sandstorm can strip an automobile clean and polish the bare metal. In Iran the summer "wind of 120 days" has even, in the course of centuries, undermined walls and buildings.

The desert imposes a specialised mode of life on its inhabitants. The motifs of life are heat and water. The heat demands loose light clothing, such as the Arab cloak or burnoose and baggy trousers; head coverings are essential, hence the turban. Except in the larger oases wood is unobtainable, and in the settlements houses are built mostly of sun-dried mud bricks or adobe. The nomadic Arabs live in tents and follow the scanty pasture with their herds; there seems to be a sort of "desert telegraph" which spreads the news of where rain has fallen and there will be pasture. The Arabs were the first exponents of "dry-cleaning," sand replacing water for the ceremonial washing enjoined by the Koran.

In the other desert regions conditions are not so severe as in the Sahara, though some of them have even less rain. In the deserts of Peru there are places where probably no rain has fallen for centuries. In the northern part of the Gobi desert the winter is extremely cold, with piercing north winds. In

less extreme conditions winter in the desert, where water is available as in Egypt, is a pleasant, healthy season.

Where the desert can be irrigated, as in Egypt, Iraq and parts of western U.S.A., it is very fruitful, the abundant sunshine and high temperatures giving rich crops, perhaps two or three times a year.

## MOUNTAIN CLIMATES

The characteristics of mountain climates are the decrease of air density and temperature and the increase of precipitation with height, the distinction between the windward and leeward sides of mountain ranges, and the local variety of climates in mountain valleys.

Rough averages of the variations of barometric pressure and air density with height are shown in the following table:—

TABLE 20.—Decrease of pressure and density with height.

| | | | | |
|---|---|---|---|---|
| Height, feet | 5,000 | 10,000 | 15,000 | 20,000 |
| *Temperate regions*— | | | | |
| Pressure, mb. | 845 | 676 | 573 | 470 |
| Density, gm./m$^3$ | 1,070 | 880 | 770 | 660 |
| *Sub-tropics*— | | | | |
| Pressure, mb. | 847 | 686 | 586 | 485 |
| Density, gm./m$^3$ | 1,020 | 850 | 745 | 640 |

Air density is directly proportional to the barometric pressure and inversely proportional to the temperature expressed in absolute degrees (° C.+273). On an extensive plateau on very hot days density may be 5–10 per cent. smaller than the figures given above.

Air density affects the performance both of human beings and of machines. The effect on humans is inappreciable below about 7,000 feet. Above this height a fuller development is noticeable in the lungs of the inhabitants, with more oxygen in the blood. Above 10,000 feet lack of sufficient oxygen begins to cause anæmia and muscular weakness in the permanent inhabitants, but even at 14,000 feet large communities exist in the Andes without suffering any apparent inconvenience. Inexperienced mountain climbers suffer from "mountain sickness"

and sleeplessness, but generally become acclimatised in a few days. The effect on machines is most noticeable in the decreased power of aircraft to take-off from high-level airfields such as those of East Africa, the lift at the same speed being directly proportional to the density. This makes a considerable difference to the possible load. Air density is also likely to affect the acceleration of vehicles driven by internal-combustion engines. On the other hand, wind pressure at the same air speed is proportional to density, so that at high speed wind resistance falls off with increasing height. The decreased density of the air on mountains to some extent counterbalances the greater strength of the wind often encountered.

Temperature decreases upwards at the rate of about 3° F. per thousand feet, but this does not apply in mountain valleys where the lower slopes are often as warm as or warmer than the valley floors. The following figures show the mean annual temperatures at different heights in southern Peru:—

| | Mollendo (coast) | La Joya | Arequipa | Puno | Vinocaya | El Misti |
|---|---|---|---|---|---|---|
| Height, feet . | 80 | 4,140 | 8,041 | 12,539 | 14,360 | 19,200 |
| Temperature, ° F. | 67·2 | 63·7 | 57·8 | 47·5 | 36·7 | 19·2 |

The annual range of temperature is very small, and the climate of places like Bogota and Quito, near the Equator at heights of eight or nine thousand feet, is often described as "eternal spring." But anything eternal can become boring!

The leeward slopes of mountains are often warmer than the windward slopes because of the warm dry winds which blow down from the ridge. The Föhn of the Alps (see p. 108) and the Chinook of the Rockies (see p. 125) are the best known examples, but similar winds are found wherever conditions are suitable. The effect of slope and aspect in the local climate of the Alps was described on p. 107.

The precipitation (rain and snow combined) depends very much on the exposure of the mountains to rain-bearing winds. On the windward side, especially where the range fronts the sea, the precipitation is very heavy, often 200 inches or more a year. On the leeward or inland side it is much less. The precipitation increases with height up to a level of 7,000–8,000 feet, but which varies with latitude, being greater nearer the

Equator and smaller nearer the poles. With increasing height the proportion of the precipitation which falls as snow increases and the zone of greatest snowfall is above that of greatest precipitation. The most favourable situation for a regular water-supply for irrigation or hydro-electric works occurs where there is abundant winter snowfall which melts gradually during the spring and summer. Heavy falls of rain are dangerous because they cause sudden floods in the narrow mountain valleys, where the streams may rise 60 feet in a few hours.

The strength of the sunlight, due to the thin air and the reflection from snow surfaces, combined with the bracing quality of the cold air and brisk winds and the beauty of the surroundings, make accessible mountain districts very suitable for sanatoria and for holiday resorts, but otherwise mountain districts are of little importance apart from their mineral wealth and, on the lower slopes, forest products.

High plateaus have more extreme climates than mountain peaks. The climate of the plateau region of North America was described on p. 126. Tibet (Appendix I, Lhasa) at an average height of over 12,000 feet, has intensely cold winters but hot summers. Eastern Tibet has a considerable summer rainfall during the south-west monsoon and a rich vegetation; the rainfall is not heavy, but is persistent; winters are dry with little snow, and the winds are strong and piercing. Western Tibet has less precipitation but more snow in winter.

ARCTIC CLIMATES (Appendix I—*U.S.S.R.*, Dikson Island, Verkhoyansk; *Alaska*, Nome; *Canada*, Chesterfield, Dawson, Hebron; *Spitsbergen*, Green Harbour).

In the polar regions the sun remains continuously above the horizon in summer and below it in winter, and this as much as the cold is the dominant feature in the life of high latitudes. Even at midsummer the sun is low in the sky, but the days are so long that the amount of heat received is comparable with that in temperate latitudes. In continental regions the winters are intensely cold, the average temperature of February being about −25° F. with extremes as low as −60° F., but the weather is generally fine and there is little snow. On flat ground the winter is long, but southerly slopes warm up quickly in spring, the snow melts early, and the soil temperature is much higher than the air temperature; such sites have a local favourable climate. The summers are short and cool with an

average temperature of about 40° F. in July, and generally dull; there are frequent but not heavy showers of rain or snow. The great curse of summer, especially in the tundra, is the plague of mosquitoes, which are active throughout the twenty-four hours.

On the ice-bound shores of the Arctic Ocean the climate is much more severe. The winters, though not so cold as in the interior, are long and dreary; the summers are very short (only a month or two), cold, foggy and rainy. At the mouths of the great rivers flowing into the Arctic Ocean the break-up of the ice in spring causes great floods and ice-jams, making the country impassable. The most favourable Arctic climates occur where the coasts are washed by a warm current, as in southern Iceland and south-western Spitsbergen. The east and west coasts of Greenland also are not especially cold in winter, and have experienced temperatures exceeding 70° F. In West Greenland the temperature is extraordinarily variable, and may change by 70° F. or more in two or three days.

Economically the most important part of the Arctic comprises Alaska, northern Canada and Labrador (Appendix I—Nome, Chesterfield, Hebron). The Arctic zone forms a narrow belt along the west and north coasts of Alaska, which broadens eastwards, the southern boundary running roughly from 70° N. in 160° W. (north-west Alaska) to 55° N. on the east coast of Labrador, and then down the coast to Belle Isle. The climate is severe; it is very cold in winter, all waterways and the soil being frozen and the tundra covered with snow packed by the wind into solid drifts. The coasts are ice-bound for much of the year and only accessible for a few months in late summer. Summer is short and cool, the temperature only rising above 50° F. in the rare warm spells. In the northern and north-eastern part of the area the ground is permanently frozen to depths of 100–200 feet, only thawing at the surface for a few inches in summer, when the surface becomes soft and marshy. The rainfall is small, but evaporation is also slight, and the numerous lakes and rivers maintain a high humidity. When the thaw comes in late spring the country is a quagmire. Western Alaska along Bering Strait is somewhat warmer than the remaining part of the area, but the climate is damp and foggy, with much snow in winter. The neighbourhood of Hudson Bay is also damp and foggy in summer, with low day temperatures. The coast of

Labrador is especially dismal, owing to the Arctic ice-drift, and here the climate improves inland. Over the whole area agriculture is only possible in a few specially favoured spots; the chief products are minerals and furs.

Life in the Arctic regions presents many problems, some of which have been overcome by war-time research. About 70 per cent. of the loss of heat from the body occurs by the ordinary processes of radiation, conduction and convection, and this loss is proportional to the area of the body multiplied by the difference between the temperature of the surface of the clothing and that of the environment (air and surrounding bodies). Hence the clothing must be such as to transmit little of the body heat. The right clothing is not so much a question of weight and thickness as of adequate insulation by air spaces. Wind adds greatly to the effect of the cold, and the loss of heat brought about by even a moderate wind is known as "wind chill." In the coldest weather it is necessary to keep out the external air, which can be done by an impervious outer garment with draw-strings at the openings of neck, arms and legs, but it is also necessary to permit free circulation of the air next the skin, to evaporate perspiration. This can be secured by wearing a "string vest"—a coarse wide-meshed net to hold the under-clothing away from the body. The main problem is then to keep the extremities warm. In a cold environment the body automatically tries to reduce its loss of heat by reducing the flow of warm blood to the limbs, and the consequent return of cooled blood. This helps to maintain the body temperature, but at the expense of the fingers, toes, nose and ears. If this process goes too far frost-bite results. For this reason it is necessary to wear properly designed gloves and footwear as well as suitable body clothing.

The loss of heat from the body has to be made good by eating a correspondingly large amount of food, especially fats and carbohydrates. For this reason and also because of the difficulty of raising crops, fish and flesh are the basis of diet. Alcohol, which lowers resistance to cold, is to be avoided. A survey of the physiological reactions to cold, with a full bibliography, is given by B. Roberts (1943).

Building on permanently frozen ground ("permafrost") is difficult, because the heat from the building thaws the ground and causes subsidence. The method found most satisfactory is

to drive wood or concrete (not metal) piles into the ground so that they project one or two feet below the surface to which thawing penetrates. The upper parts of the piles should be smooth and greased, so that they are not disturbed by movements of the thaw layer. The floor of the building must, of course, be clear of the latter. Water supply is a difficulty, especially where the lakes and rivers freeze solid; where possible it is desirable to instal a large tank which can be kept permanently heated throughout the winter. In many Arctic regions there is plenty of potential water-power for hydro-electric generators, but this is not available in winter when it is most required. Transport to isolated communities in Canada has been mostly by air, but the Canadian Government has developed a "snow-mobile" which has proved satisfactory and is being put into manufacture.

# PART II

# CLIMATE AS AN ENEMY

# CHAPTER VIII

## CLIMATE AND THE DETERIORATION OF MATERIALS

IN this chapter we discuss the effects of climate on the physical, chemical and organic structure of materials, especially manufactured goods. Mechanical effects are due mainly to extremes of temperature and especially to excessive heat. The effect of frost on roads and buildings was discussed in Chapter II (p. 80). Chemical effects (corrosion) and organic effects (growth of mould) are due mainly to the combination of high temperature and high humidity.

### SOLAR HEAT AND HIGH TEMPERATURES

The "temperature" shown on climatic charts is the "shade temperature" or temperature inside a "screen," which is a box freely ventilated on all sides. The temperature of a body exposed to radiation from the sun is generally much higher. It depends on the solar radiation, the nature of the surface of the body, particularly its colour, heat capacity and conductivity; the nature of the surroundings, which determine the amount of heat received by reflection and radiation from surrounding objects; and the loss of heat by conduction to the air, which depends on the air movement. Of these factors one of the most important is the incoming solar radiation. As explained in Chapter II this depends on the elevation of the sun, *i.e.* the latitude and season, and on the purity and dryness of the air. Colour is equally important; in hot dry climates a non-conducting black surface, such as a cloth, may be 30–40° F. hotter than a similar white surface; coloured surfaces are intermediate in temperature. In general a matt surface absorbs more heat than a polished one, but this effect is less important than that of colour.

The *surface* of material which is a poor conductor of heat, such as wood or plastic, will become hotter than a metal surface which is not insulated from the ground, but it will also be a better protector for the space which it covers. The worst

construction for a store is a single iron roof, of a dark colour, supported on non-conducting walls, with no insulating layer or ventilating holes below it.

As an illustration of the physical problem involved let us consider a thin plywood container, painted black and mounted clear of the ground, on a calm, clear day with a vertical sun. We will assume (C. E. P. Brooks, 1946*b*) that the container is large enough for the temperature of the ground beneath to equal the shade temperature, say a maximum of 50° C. (122° F.),

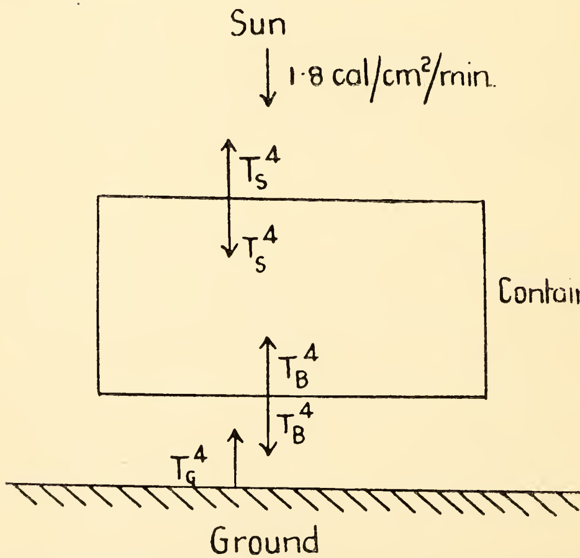


Fig. 14.—Radiation to and from a container with thin walls.

that the radiation on the upper surface is 1·8 cal./cm.²/min., all of which is absorbed, and that there is no transfer of heat otherwise than by radiation (see Fig. 14).

Let $T_G$ be the temperature of the ground, equal to 50° C. or 323° A. (temperature in degrees absolute is 273 plus temperature in ° C.). Let $T_B$ be the temperature of the lower surface of the container and $T_S$ that of its upper surface, the temperatures of the internal and external surfaces being identical in each case (this is approximately true for very thin plywood). The radiation from a surface is proportional to the fourth power of its absolute temperature. The upper surface $T_S$ is receiving radiation from the sun (1·8 cal./cm.²/min.) and

from the bottom surface at the rate of $\sigma T_B^4$ where $\sigma$ is the radiation constant, and is sending out radiation on both sides at the rate of $\sigma T_S^4$. Similarly the bottom surface is receiving radiation from the top surface at the rate of $\sigma T_S^4$ and from the ground at the rate of $\sigma T_G^4$, and is sending out radiation from both surfaces at the rate of $\sigma T_B^4$. Then assuming that each surface has reached equilibrium with its surroundings, *i.e.* is radiating as much heat as it is receiving,

$$\sigma T_B^4 = \frac{\sigma}{2}\left(T_S^4 + T_G^4\right) = \frac{\sigma}{2}(T_S^4 + 323^4)$$

$$\sigma T_S^4 = \frac{1}{2}\left(1{\cdot}8 + \sigma T_B^4\right).$$

If the ground and plywood surfaces radiate as black bodies, $\sigma = 82 \times 10^{-12}$gm.cal./cm.$^2$/min. The solution of these two equations gives

$$T_S = 368^\circ\ A. = 95^\circ\ \text{C. or } 203^\circ\ \text{F.}$$
$$T_B = 330^\circ\ A. = 75^\circ\ \text{C. or } 167^\circ\ \text{F.}$$

Experiment has shown that the mean temperature of the air inside the container will be some degrees lower than the mean of the upper and lower surfaces, *i.e.* between 80° and 85° C. (185°–194° F.).

If the sun is not vertically overhead we can allow for the increased absorption due to the longer path of the rays through the air by the method described in Chapter II (p. 59), but as we are dealing with the hottest, clearest days, and as we have to include also the effect of some of the scattered solar radiation, a reasonably close value for the transmission coefficient would be 0·9. The maximum temperatures of the top and bottom surfaces of an empty plywood container in different latitudes, calculated in this way purely from the exchange of radiation are:—

| Latitude | 0–30° | 40° | 50° | 60° |
|---|---|---|---|---|
| Top surface, ° F. | 203 | 194 | 181 | 163 |
| Bottom surface, ° F. | 167 | 158 | 145 | 127 |

Temperatures calculated in this way are, however, too high. No body absorbs *all* the solar radiation falling on it, and there is always some loss by conduction to the air.

The following table shows some observed temperatures of

non-conducting surfaces exposed to the sun, compared with the maximum temperatures in the shade:—

| | Latitude | Temperature ° F. | |
|---|---|---|---|
| | | Observed | Shade max. |
| Bare sand, Loango | 5 | 183 | (120) |
| Black cloth, Khartoum | 15½ | 184 | 118 |
| Black soil, Poona, May | 18½ | 148 | (99) |
| Bare sand, Sahara | (25) | 173 | (120) |
| Aircraft wing, Tucson, Arizona | 32 | {215<br>193 | 118 |
| Balloon, U.S.A. | ? | 152 | 78 |

The maximum possible temperature calculated from the balance of radiation is about 200° F. for each of the first five. The outstanding observation of 215° F. at Tucson, Arizona (Madison, 1944), is more than 20° F. above the next highest figure of 193° F. at the same place, and must have been due to a very unusual combination of circumstances. Apart from this the readings are mostly 60°–70° F. above the shade maxima and 10°–20° F. below the temperature calculated from the exchange of radiation with no allowance for loss by conduction.

In the observations on the surface of a balloon (Washington, Bureau of Standards), the incoming solar radiation at the time was measured. The surface temperature calculated from it by the method described above was 158° F., which is only 6° F. above the temperature actually observed. In the Sahara there is a good deal of dust haze which reduces the intensity of the radiation. At Poona in May there is a good deal of water vapour in the air, and also the soil probably had a higher conductivity than loose bare sand. The readings at these two places are therefore relatively low.

In the upper layers of air inside a closed container heated from above the temperature decreases downwards, but the lower layers have a nearly uniform temperature equal to or very little above that of the bottom skin. The actual distribution depends on the size, shape, material and contents of the container as well as on the temperatures of the top and bottom skins, but the *type* of distribution is indicated in Fig. 15. If the sun is not directly overhead, so that one side of the container is in sunshine and the other in shadow, the effect of the unequal heating is to raise the surfaces of equal temperature somewhat

on the warmed side and depress them somewhat on the cool side; if the heating on the two sides is very unequal a circulation of air will probably be set up which will tend to equalise the temperatures throughout the container. The average temperature inside the container is lower than the mean of the top and bottom surfaces, especially if the sun is nearly overhead.

The temperatures reached by solid conducting bodies such as steel rails are probably similar to or slightly lower than the average inside temperatures of containers exposed in the same way, but comparable data are few. A steel rail painted black, exposed at Panama, reached a temperature of 129° F. with a shade air maximum of 88° F. (H. G. Cornthwaite, 1920).

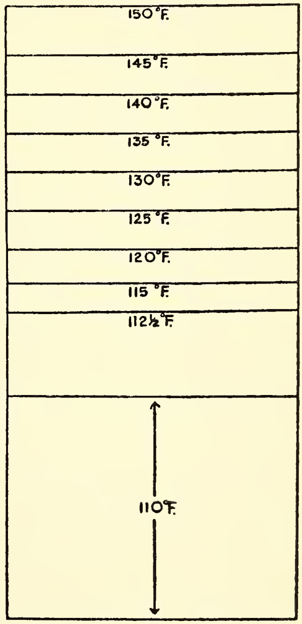


Fig. 15.—Temperatures inside a container heated on top surface.

The "black-bulb" thermometer in vacuo is often used as a measure of the highest temperature which would be reached by an object exposed to the sun. This instrument consists of a self-registering maximum thermometer, the bulb of which is covered with lamp-black and enclosed in a larger glass bulb which is exhausted of air. The readings of these instruments are rather unreliable, depending on the size of the thermometer bulb, the constitution of the black coating, the composition of the glass sheath and the completeness of the vacuum, but in general they record temperatures about equal to those found inside large unventilated containers, and much lower than those of non-conducting upper surfaces.

Fig. 16 is an attempt to estimate the distribution of the highest temperatures which would be reached in an average year by horizontal non-conducting surfaces exposed to the sun. It is based on such actual observations as are available, on readings of black-bulb thermometers increased by 20° F., and

on the mean annual maxima of shade air temperatures; the latter were charted by C. E. P. Brooks and G. L. Thorman (1928). The readings are considered to be substantially independent of height above sea-level, since the greater intensity of solar radiation with increasing height is balanced by the lower air temperature and consequent greater loss by conduction.

The mechanical effects of high temperature may be increased by the chemical effects of strong sunlight and especially of ultraviolet radiation. These are rather obscure, but according to W. M. H. Schulze (1941) strong UV radiation causes lacquer to become brittle, coloured fabrics to bleach and soft rubber to crack. UV radiation is especially strong in clear, dry air at high levels.

*Effect of colour.*—We owe to G. W. Grabham (1921) a series of valuable experiments on the effect of colour. The general result of these was that black and dark objects took up higher temperatures than white or light-coloured objects. Grabham expressed his results by taking the difference between the temperatures of black and white objects as 100 and expressing the temperature of any object of another colour as a percentage of this difference. For our purpose, however, it seems better to express the difference between a black object and the corresponding shade maximum temperature as 100, and the excess of a coloured object over the shade maximum as a percentage of this. Table 21 shows the effect of colour, calculated in this way, based on the results of a number of experiments in hot countries. Grabham's experiments include: the temperature under one thickness of thin cloth, with a number of thicknesses beneath; and thermometers inserted through corks in small cylindrical tin flasks laid on a doubled woollen blanket. Experiments with thermometers in square flat tins were carried out by W. F. Harvey (1930) at Kasauli in the Punjab (quoted by Sir A. Castellani, 1938). The experiments with steel rails were made by H. G. Cornthwaite (1920) and those with different coloured soils at Poona by L. A. Ramdas and R. K. Dravid (1936). The latter gave the weekly mean temperatures of the surfaces at 2 p.m.; corresponding shade temperatures are not available and the figures at the foot of the table are the mean daily shade maxima in January and May at Poona. Grabham's figures for cloths and painted flasks incorporate

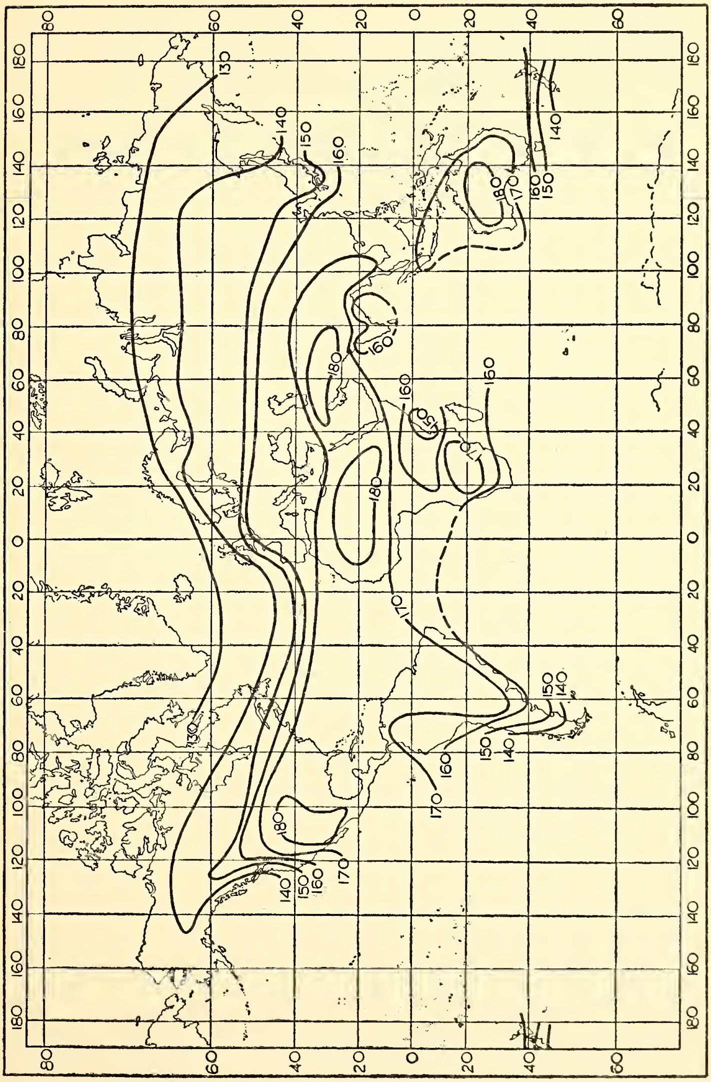

Fig. 16.—Probable maximum temperature of a surface exposed to the sun.

experiments on several different days, but the results are in general very consistent.

TABLE 21.—Temperatures of different colours as percentages of "black" minus "shade max."

| Colour | Cloth | Painted tins | | Steel rail | Soil—Poona | | Mean |
|---|---|---|---|---|---|---|---|
| | Khartoum | Halfa | Kasauli | Panama | Jan. | May | |
| Black, ° C. | 84·3 | 70·8 | 58·0 | 53·9 | (53) | 64·4 | |
| ° F. | 184·0 | 159·0 | 136·0 | 129·0 | (127) | 148·0 | |
| | % | % | % | % | % | % | % |
| Black | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| Dark blue | 89 | — | — | — | — | — | 89 |
| Brown | — | 88 | — | — | — | — | 88 |
| Cement wash | — | 85 | — | — | — | — | 85 |
| Green | — | 79 | — | 90 | — | — | 85 |
| Plain metal | — | 73 | 90 | — | — | — | 81 |
| Grey, ash colour | — | 79 | — | — | 70 | 76 | 75 |
| Khaki, light brown, yellow brown | 76 | 72 | — | — | 69 | 78 | 74 |
| Red | — | 69 | — | 66 | 77 | — | 73 |
| Pale blue | 72 | — | — | — | — | — | 72 |
| Straw | — | 54 | — | — | — | — | 54 |
| Cream | — | 49 | — | — | — | — | 49 |
| White | 42 | 40 | 54 | 58 | 42 | 40 (30) | 46 |
| Shade max, ° C. | 42 | 42 | 34 | 31 | (30) | (37) | |
| ° F. | 108 | 108 | 93 | 88 | (86) | (99) | |

These figures may be summarised roughly as follows to show the relative effect of colour:—

| | |
|---|---|
| Black | 100 |
| Dark blue, brown, green | 85–90 |
| Grey, cement wash, ash, plain metal | 75–85 |
| Khaki, red, light brown, pale blue, aluminium paint | 70–75 |
| Pale colours (straw, cream) | 50–55 |
| White | 40–50 |

Boxes with glass sides and tops gave about the same temperatures as blackened tins. Different whites react very differently; *e.g.* in one experiment with painted flasks the standard white gave a percentage of 39 and white enamel one of 49. The white-painted steel rail in Panama appears to have given an abnormally high temperature for this colour; on the other hand, in another series of observations at Poona in January 1934 a

surface of powdered white chalk gave a percentage of only about 30 (added in brackets in the table). The range shown by other colours is also no doubt due mainly to differences in the shade of colour and the texture of the surface. Unpainted, horizontal steel rails reached the following temperatures at Agra, India, and in Hungary:—

| | Max. temp. of rail | Shade max. |
|---|---|---|
| Agra, India | 61° C. (142° F.) | 44° C. (111° F.) |
| Hungary | 53° C. (127° F.) | 33° C. (91° F.) |

Harvey remarks that the high temperatures reached by water in closed receptacles are lethal to micro-organisms, while those of water open to the air are incubation temperatures. He also found that sprinkling water at 45° C. (113° F.) on a tin at 45° C. every ten minutes reduced the temperature by as much as 10° C. (18° F.).

The most important effects of high temperature acting alone appear to be chiefly mechanical, such as expansion, buckling of metal rails, blistering of paint work, but the effects on viscosity or rigidity, such as weakening of glued joints, softening of gelatine films, etc., are scarcely less important. In some materials, such as rubber, there is a critical temperature above which a non-reversible chemical change takes place. The most important effect on rubber however is oxidation under the influence of strong sunlight (J. Crabtree, 1948).

The speed of most chemical reactions increases with temperature at an increasing rate. "Dunn's equation" is in the form

$$\log A = -C/T + K$$

where $A$ is the speed of reaction and $T$ is the absolute temperature; $C$ and $K$ are constants. For the range of action met with in nature it is convenient to express the rate at 0° C. (32° F.) as unity. Then writing $t = T - 273$ (*i.e.* $t$ in ° C.), we have

$$A - a^{t/T}.$$

The chemical reactions with which we are concerned are negligible below −10° C. and are mostly concentrated in the higher ranges of temperature met with in nature. The effective range of $t$ is therefore small compared with $273 + t$, where $t$ is of

the order of 30° C. Thus a sufficient approximation is given by replacing $T$ by its mean value and then writing

$$A=\alpha^t \quad \text{where } \alpha=a^{1/T}.$$

The ratio of $\alpha^t$ to $\alpha^{t+10}$ is termed the *temperature coefficient* of chemical reaction or $\phi_{10}$, and is generally found to lie between 2 and 3. Actually $\log \phi_{10}$ is inversely proportional to $T\,(T+10)$ and decreases as temperature rises. It varies, however, with different materials; for corrosion of iron in pure dry air it is only about 1·2 (data from W. H. J. Vernon, 1935). For most actions involving water it appears to be very close to 2.

Flow resulting from high temperature may be of importance. From such few figures as I have been able to find it appears that the fluidity $F$ of viscous substances can be represented with fair accuracy by an expression of the form

$$F=a\times b^t$$

similar to that for chemical effects. Examples for two substances are:—

| | a | b | "Temperature coefficient" |
|---|---|---|---|
| Glycerine | 0·02 | 1·09 | 2·4 |
| Pitch | $2\times10^{-12}$ | 1·277 | 11·5 |

It is well known that many organic actions, such as the growth of bacteria, increase with temperature in much the same way as chemical actions. There is generally an optimum above which the activity falls off very rapidly (sterilising effect), but this optimum is in most cases above the maximum temperature likely to be experienced in the natural environment. It is believed that the temperature coefficient is in general about 2, *i.e.* the rate of bacterial action doubles for each rise of temperature by 10° C. (18° F.), but it varies considerably with the temperature. D. Snow, J. A. B. Smith and N. C. Wright (1944) found that on feeding stuffs impregnated with nitrogen compounds, moulding appeared after 128 days at 15° C. and after 60 days at the optimum temperature of 22° C. (temperature coefficient 2·95). At 37° C. there was no moulding. On the other hand, figures given by D. Snow, M. H. G. Crichton and N. C. Wright (1944) for locust beans at 75 and 80 per cent. relative humidity at temperatures of 15·5 and 20° C. give a value for the temperature coefficient of only 1·4.

A full discussion of the effect of high temperatures on electrical apparatus is given by W. M. H. Schulze (1941), and this should be consulted for details. Heat may affect the insulation of electrical apparatus, and all insulating materials for use in hot countries should be stable up to at least 90° C. (194° F.).

## THE EFFECT OF HUMIDITY

Many organic materials react to the *relative humidity* of the air, absorbing moisture when the humidity is high and releasing it when the humidity is low, with corresponding changes of volume. The final result is independent of the air temperature, though the rate of reaction increases with temperature. This property of expansion with increasing relative humidity is made use of in the "hair hygrometer," which measures the relative humidity by the lengthening or shortening of a bundle of human hairs. High relative humidity leads to warping and swelling of wood, paper, leather, etc., low relative humidity to shrinking and cracking. In very humid climates and in climates with a large diurnal range of temperature any machine components such as electrical connections which are sensitive to humidity should if possible be enclosed in airtight waterproof covers of glass, porcelain or plastics.

The effect of humidity on the physical properties of paper has been investigated by F. T. Carson (1944). With increasing humidity paper expands by different amounts in different directions, causing distortion and difficulties of registration in colour printing. At low humidities paper becomes brittle and readily cracks along folds.

The reaction of paper, leather and similar materials to increasing humidity often increases rapidly when the relative humidity rises above 65 or 70 per cent. With some materials, such as hair, the absorption is increasingly rapid with increasing relative humidity through the whole range from 0 to 100 per cent. In others, such as leather, there are three stages: (1) from 0 to 15 or 20 per cent. absorption of water is moderately rapid; (2) from 20 to about 65 per cent. absorption is slow; (3) above 65 per cent. absorption increases more and more rapidly. A typical curve (average of curves for untanned hide and various leathers given by J. R. Kanagy, 1947) is shown in Fig. 17.

Many organic materials, such as tobacco, sugar and cereal

products, glue, etc., which contain moisture, have a critical relative humidity at which they remain in equilibrium and retain their properties. At higher humidities they absorb moisture, and at lower humidities they dry out, both processes often being accompanied by deterioration. It is important to ascertain this critical humidity and ensure that it is maintained in the store.

H. W. Eades (1945) found that the rate of rusting of cans

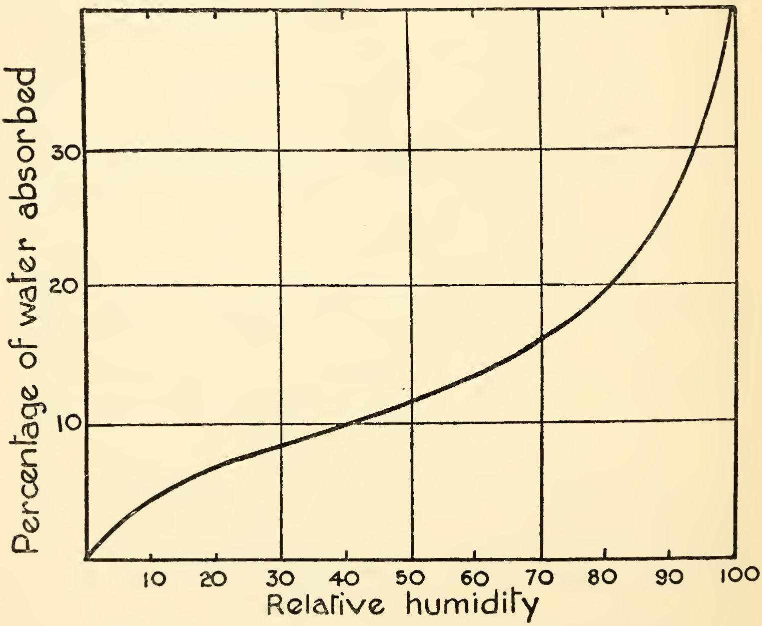


Fig. 17.—Absorption of water-vapour by leather.

stored in wooden boxes increased directly with the moisture content of the wood above 17 per cent.; below this figure rusting was slight and below 14 per cent. practically absent; the species of wood was unimportant. Dehumidification, *e.g.* by silica gel, prevented rusting.

If kept for too long in a high relative humidity many organic substances go mouldy even at moderate temperatures. In most cases the critical humidity is 65–70 per cent. Fig. 18 shows a number of curves of rate of growth of mould in air streams of different relative humidities, given by D. Snow and collaborators (1944, 1945) and by N. C. Wright (1944). The papers

were kindly sent to me by Dr. Wright. The data are given as the number of days before formation of mycelium and before fructification; to get the rate of moulding I have taken the reciprocals of these and expressed them as percentages of the value at 80 per cent. humidity. The curves are:—

(1) Cereal feeding stuffs with urea mixture (moulding) (Snow, Smith and Wright). Time at 80 per cent. R.H. 21 days.

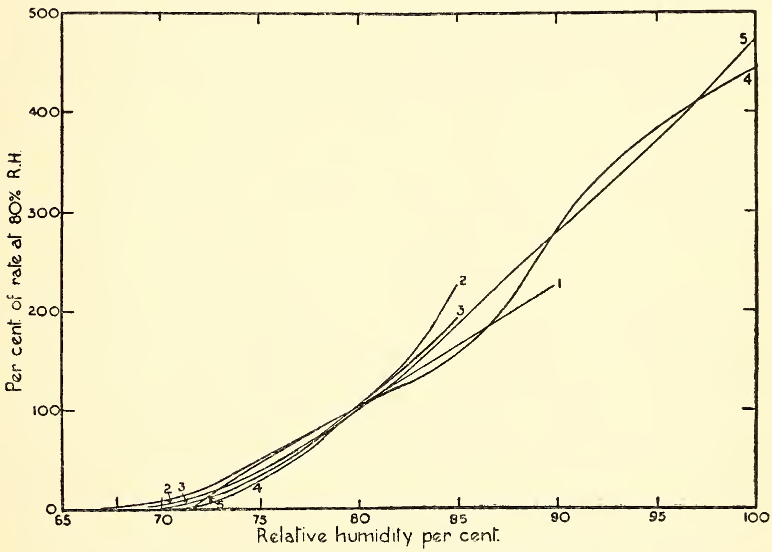


Fig. 18.—Rate of growth of mould at different humidities.

(2) Artificially dried grass. Mycelium (Wright) 18 days at 80 per cent.
(3) Ditto, fructification (25 days at 80 per cent.).
(4) Locust beans, 15·5° C., mycelium (Snow, Crichton and Wright) (22 days at 80 per cent.).
(5) Ditto, 20° C. (19 days at 80 per cent.).

The figures for oats were stated to be similar to those for locust beans.

The curves are in general agreement, and it is seen that the growth of mould does not begin until the relative humidity exceeds 64 per cent., increases slowly to about 70 or 72 per cent. and then rapidly. It is probable that the rapidity of increase with increasing humidity falls off above about 90 per cent.

Snow and Wright (1944) found that loss of dry matter from stored bran due to enzymatic and microbial activity at 20° C. increased slowly as humidity rose from 64 to 84 per cent. and very rapidly above 84 per cent.

### THE EFFECTS OF COMBINED TEMPERATURE AND HUMIDITY

Many chemical and organic actions require the presence of a moist atmosphere, and apart from any purely thermal effect the rate presumably depends on the quantity of water vapour available. In saturated air the moisture content nearly doubles for each rise of temperature by 10° C.; actually the coefficient is not constant, but decreases from 2·0 between −10° and 0° C. to 1·68 between 30° and 40° C. Between 20° and 40° C. the weight of water vapour $e$ in grams per cubic metre can be represented on the average by

$$e = 5{\cdot}9 \times 1{\cdot}054^{t}$$

where $t$ is the temperature in ° C. The effect of water vapour depends, however, not only on the quantity present in the air, but also on the willingness of the air to part with it, *i.e.* on the relative humidity. In general, actions involving water vapour do not occur with a relative humidity below 60–70 per cent., though the figure probably varies widely. The combined effects of high temperature and high humidity may be divided into chemical and organic effects.

The main chemical effects of high humidity at a high temperature are rusting and tarnishing of metals. In experiments on the rusting of iron W. H. J. Vernon (1935, 1945) found that action was very slow until the relative humidity reached about 65 per cent., and then increased rapidly at an almost linear rate with increasing relative humidity, until it was retarded by the formation of a protective crust. N. Cabrera and J. Hamon (1947) found that in pure air the oxidation of aluminium at constant temperature was appreciable in dry air, but increased with relative humidity at an increasing rate. In dry air oxide is formed, in damp air hydroxide. In the presence of ozone the increase with humidity was very rapid when the relative humidity was above 50 per cent.

Organic effects such as rotting and mildewing also depend on both temperature and humidity; mould growths, for example,

do not occur with relative humidities below about 70 per cent., but with high temperature and saturated air their growth is very rapid.

The general expression for both chemical and organic effects involving the presence of water vapour at a high temperature may be put in the form

$$A=b\frac{(H-k)}{100}\,(1\cdot054)^t$$

where $A$ is the rate of action, $H$ is the relative humidity, $t$ is the temperature in ° C., $b$ and $k$ are constants. An alternative form is

$$A=b\,(V-V_t)$$

where $V$ is the observed vapour pressure and $V_t$ is the vapour pressure at the same temperature $t$ but with relative humidity $k$.

It is to be remarked that $H$ is not necessarily the relative humidity in the free air, but depends on the amount of water vapour in the air, the surface temperature of the body being attacked, and any additional sources of water vapour. Damp wood in an unventilated environment, for example, may saturate the air in contact with it and provide a suitable medium for fungoid growth, even where the free air is below the critical humidity.

The rate of action also varies with time in a complex way. In some cases, *e.g.* corrosion of metals, a protective crust is soon formed, after which the action slows down. In organic decay, on the other hand, the rate of action may speed up with time as the surface of decay or concentration of bacteria or fungus spores increases.

Experiment showed that the sum of the values of $1\cdot054^t(H-65)/10$ for the twelve months has a value of about 100 in the worst tropical conditions. I have therefore adopted this expression as a standard index number to define the rate of deterioration of materials due to temperature and humidity. Values were calculated for a number of places with suitable averages of temperature and humidity, and a chart based on these is shown in Fig. 19. In using this chart it must be remembered that in islands and places of high relief the index may vary rapidly from place to place; in a world chart it is possible to present only a broad generalisation. The chart

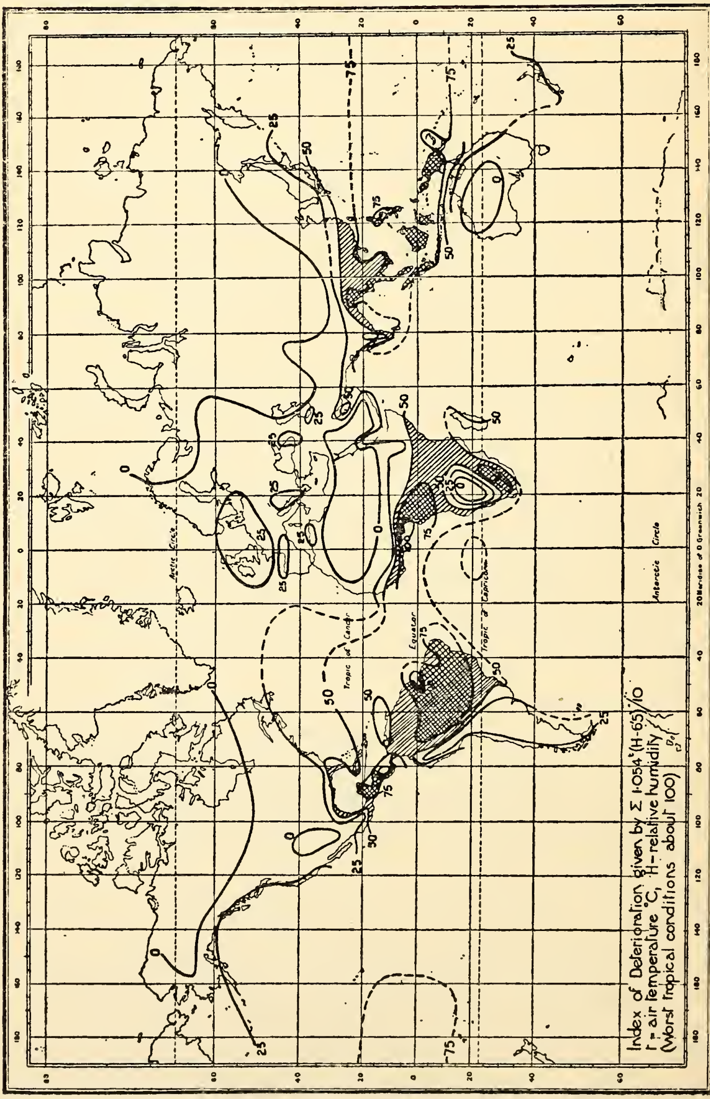


Fig. 19.—Index of deterioration.

does not take account of atmospheric impurities which greatly increase chemical deterioration (see Chapter VIII).

Corrosion of metals can be prevented to some extent by coating the surface with protective varnish, but any crack or pit in the varnish allows corrosion to spread rapidly beneath it. The coating may be broken by channelling due to rain; a more insidious process is the adherence of small animal or vegetable fragments to the surface. These go mouldy and the mould in time attacks the varnish, setting up centres of corrosion.

The values of the deterioration index charted in Fig. 17 take no account of the diurnal variation of temperature and humidity, but this may be important. Although chemical and organic effects are retarded at low temperatures a large diurnal range of temperature may cause fresh supplies of moisture to enter a container which is not completely air-tight. The daily range in a container exposed to radiation by day and night may exceed 40° C. This means that more than 10 per cent. of the contained air is expelled during the day and replaced at night by fresh air which may be nearly or quite saturated. Influx of this moist air may well result in the deposition of free moisture within the package. It is not unlikely that the clotting of finely ground material is largely due to this daily interchange of air. The effect is especially marked if the material is at all hygroscopic. The corrosion of metals and the deterioration of materials affected by moisture are accelerated by the deposition of dew, which is very heavy in the open in some tropical countries, especially where there is a large daily range of temperature. Dew forms even in dry regions such as North Africa and central India where the deterioration index given by the monthly values of temperature and humidity is small or zero, and this probably accounts for the deterioration and corrosion which is sometimes observed there.

Condensation often occurs in transit when the goods are loaded in bulk in a cold climate and later exposed to warm moist air. Water collects on flat surfaces, and H. W. Eades (1945) recommends packing of tins on their sides to avoid formation of pools on the flat tops. Lacquering is a partial cure for rusting, but the flanges or rims form weak spots; dehumidification of the store or cargo space of ships is the best preventive.

# CHAPTER IX

## ATMOSPHERIC POLLUTION

MAN is himself responsible for one of his greatest troubles, the pollution of the atmosphere by the products of combustion, especially the burning of coal. These are injurious to the health of man and animals and to plant life; they attack stone and metal, and the deposit of soot makes it difficult to maintain standards of purity in products such as confectionery. It has been estimated (A. Parker, 1945) that about one-fortieth of the coal burnt in domestic grates goes up the chimneys; factories are much better, but even there nearly one-eightieth of the coal burnt goes into the air. A detailed account of the effects of smoke on health, plant life, buildings, etc., and of methods of prevention is given by A. Marsh (1947), based mainly on the work of the Atmospheric Pollution Committee of the Department of Scientific and Industrial Research.

Atmospheric pollution takes the form of tar, ash and other solid particles, some of which may be hygroscopic, and injurious gases, especially sulphur dioxide. The corrosive effect of impurities is greatly magnified by high humidity. Thus W. H. J. Vernon (1935) showed that at 99 per cent. relative humidity air with 0·01 per cent. of $SO_2$ is thirty-five times as corrosive of iron as is pure air. Moreover, the effect of $SO_2$ is enormously magnified by the presence of particles such as charcoal, and if these are screened off rusting is slow. Particles of charcoal in conjunction with $SO_2$ are by far the most corrosive; curiously, chemically active particles such as ammonium sulphate are less dangerous, but these and even particles of silica increase the action of $SO_2$ to some extent. Apart from that the effect of acid impurities increases nearly in proportion to their concentration. The concentrations of $SO_2$ met with in the open rarely exceed $1 \times 10^{-5}$ per cent., or one part in ten million.

In the open the quantities of water vapour (at a given temperature and humidity) and impurities available for corrosion depend on the wind velocity. The effect of wind in increasing corrosion can probably be represented by the factor $(1+bW)$ where $W$ is the wind speed in miles per hour, and $b$ may pro-

visionally be taken as 0·067. The effective wind velocity is the air movement at the surface of deterioration, and in enclosed spaces with only a very slow interchange with outside air, $W$ is practically zero.

The combined effect of temperature, humidity, atmospheric impurity and wind may be expressed by the general equation

$$A = a\alpha^t + b\frac{(H-65)}{100}(1{\cdot}054)^t(1+cI)(1+0{\cdot}067W)$$

where $A$ is the rate of deterioration of a fresh sample, $t$ is the temperature in ° C. at the surface of deterioration, $H$ is the relative humidity at temperature $t$, $I$ is the concentration of effective impurities, bacteria or fungus spores, and $W$ is the effective wind velocity in m.p.h.; $a$, $\alpha$, $b$ and $c$ are constants to be determined in each specific case. When $H$ is less than 65 per cent., $H-65$ is taken as zero for surfaces affected by moisture.

Another cause of deterioration in the open is rain containing impurities, especially $SO_2$. It is possible that in some cases this completely outweighs that due to water in the form of vapour.

Hints on the minimising of corrosion due to atmospheric pollution are given by J. C. Hudson (1948). One recommendation is that paint should as far as practicable be applied when the relative humidity is below 70 per cent., *i.e.* in suitable dry weather for outdoor painting and in heated rooms for indoor painting. Flame cleaning, followed by painting while the surface is still warm, is also a good method for existing badly corroded structures. Acid-resistant enamels are the best protection against an atmosphere polluted by sulphur dioxide.

The action of atmospheric impurities on building materials has been described by R. J. Schaffer (1938–9). There are two main effects. First, soot, especially tarry matter, adheres to the surfaces, causing discoloration of walls and loss of light from windows and reflecting surfaces. This involves expense in frequent painting and cleaning. Secondly, sulphur dioxide and ammonium sulphate attack the carbonates of lime and magnesia which make up limestones and magnesian limestone. The Houses of Parliament are constructed of magnesian limestone, which the atmosphere of London converts into Epsom salts. Siliceous materials are not attacked, but calcareous sandstones, which are very durable in the country, disintegrate quickly in large towns. The soluble sulphates and carbonates formed by the action of

$SO_2$ and $CO_2$ on limestone are brought to the surface when the stone dries off after rain and form crusts. Where these are broken decay proceeds rapidly and unsightly holes are formed.

In addition to its effect on buildings, dirt in the air cuts down the light and heat received from the sun, especially in winter, and this weakens the health of town-dwellers. Fig. 20 shows a cross-section of London, comparing the duration of bright sunshine in winter with the deposits of atmospheric pollution. This shows that London's coal consumption cuts down the sunshine in the centre of the city by about 100 hours in the three winter months. Over the year as a whole the loss is about 300 hours. In addition there is a considerable loss of heat even when the sun appears to be shining strongly. At Leicester (A. R. Meetham, 1948) the loss of ultra-violet radiation in winter was found to be almost exactly proportional to the amount of atmospheric impurity. A striking indictment of coal smoke as an enemy of society is set out in the pamphlet "Guilty Chimneys," issued by the National Smoke Abatement Society.

## THE DISTRIBUTION OF ATMOSPHERIC POLLUTION

The main sources of atmospheric pollution are the large towns, both factory chimneys and the open fires of residential buildings contributing to it. From the towns it is carried by the winds. The coarser solid particles mostly fall to the ground within a mile or so of the source, the finer solid particles are carried much farther but eventually sink to the ground under their own weight, and the gases remain in the air until they are brought down by rain, but at a distance from the source their concentration is so weakened by diffusion that they become innocuous. For many years measurements of atmospheric pollution have been made by means of "pollution gauges" at a constantly growing number of places in Great Britain. These are large porcelain funnels with a surface area of four square feet, which collect the material falling into them or carried in by rain; the deposits accumulate in a large bottle and are analysed monthly. The measurements are published in the Annual Reports of the Advisory Committee on Atmospheric Pollution, published by the Department of Scientific and Industrial Research. They are given in metric tons per square kilometre; one metric ton weighs 2204·6 lbs. and is therefore

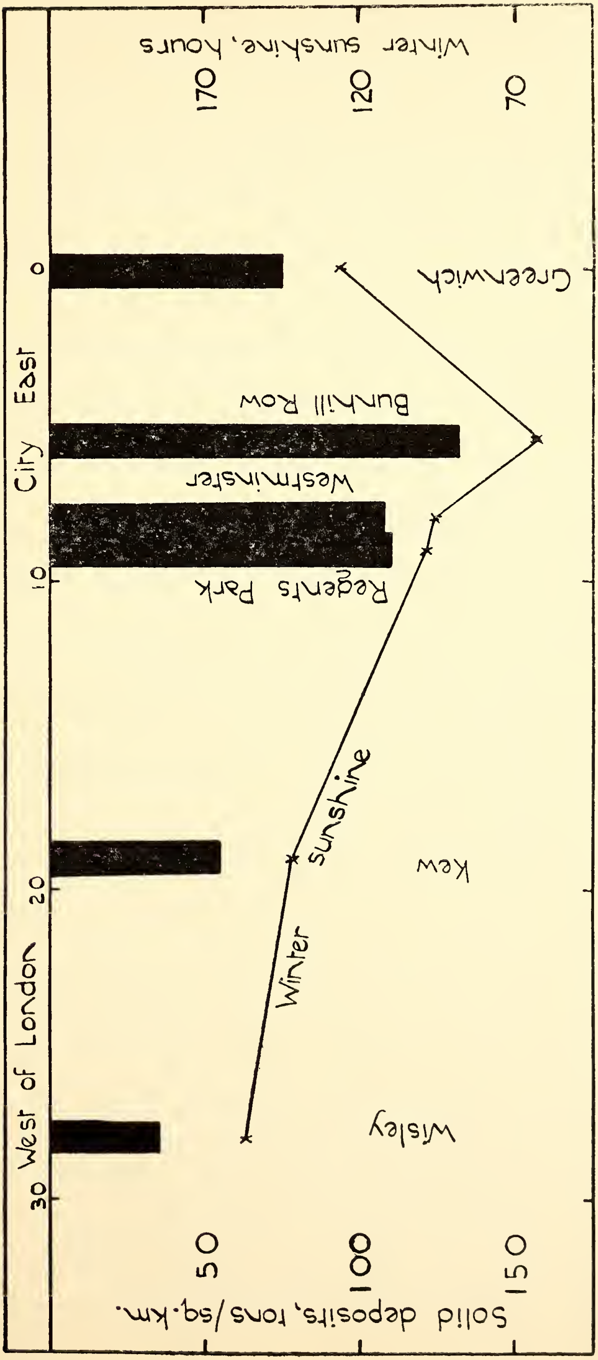


Fig. 20.—Section across London, west to east, to show how pollution affects winter sunshine.

slightly less than the English ton of 2,240 lbs. One metric ton per sq. km. equals 2·56 English tons per square mile or 9 lbs. per acre. These gauges have been installed mainly in large towns, and so far we have no information about the atmospheric pollution in Wales, south-west England, Kent and East Anglia.

The distribution of solid precipitates in Britain, and those brought down by rain, was studied on the basis of these reports by C. E. P. Brooks (1948). The total amount of matter involved is very large, as is shown by the following table for England:—

TABLE 22.—Atmospheric pollution in England.

| | Area, square miles | Deposits, tons per sq. mile per year | Total deposits, tons | Products of coal, tons |
|---|---|---|---|---|
| London . . | 425 | 260 | 111,100 | 92,400 |
| 91 other towns . | 1,490 | 200 | 301,080 | 235,460 |
| Country . . | 47,800 | 85 | 4,088,700 | 1,982,400 |
| Total . . | 49,715 | 91 | 4,500,800 | 2,310,260 |

The total deposit over the country as a whole is made up in nearly equal proportions of the products of coal combustion and of other material such as road dust, organic matter, smoke of bonfires, etc. In open country the "other material" which I have termed "country pollution," is estimated to account for slightly more than half the total deposit, but in towns the great bulk of the pollution is due to the incomplete combustion of coal.

The general distribution of deposits over the country is shown in Fig. 21, which is based on the measurements of pollution gauges either well away from large towns or to the west or south-west of them. It shows three main areas of pollution, in the Clyde Valley, the industrial belt of Lancashire and West Yorkshire, and the London area, with subsidiary centres in Tyneside and near Birmingham. The distribution of pollution in towns could not be shown on this map because of the very local nature. In the centre of a large town and for about a mile to the eastward the annual deposits may amount to from 130 to over 200 tons per sq. km. or from 340 to over 500 tons per square mile. From this dirty centre the amounts decrease slowly eastwards and rapidly westwards and south-westwards. A composite map showing the distribution around a number of

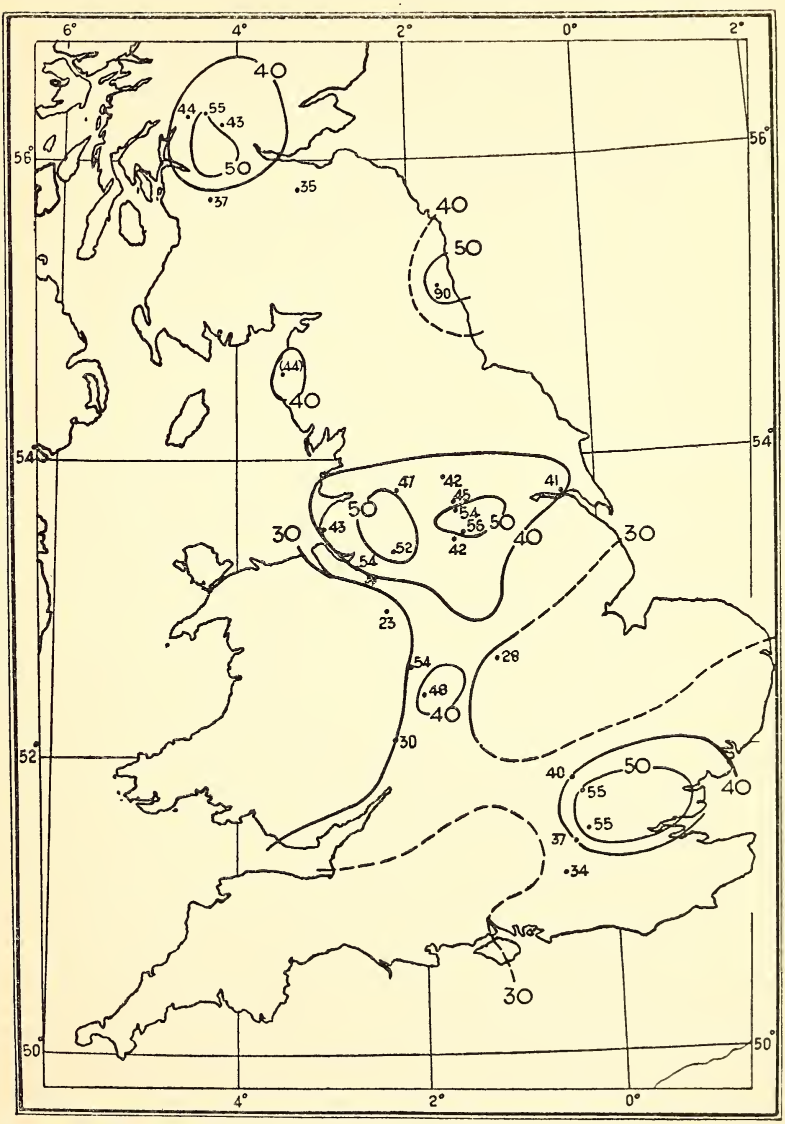


Fig. 21.—Sketch map to show distribution of total solid deposits (metric tons per sq. km.) per annum over open country and to windward of main centres of pollution.

large towns as a percentage of that in the centre is shown in Fig. 22. In any individual town the distribution is modified by the topography and by the presence of local sources of pollution.

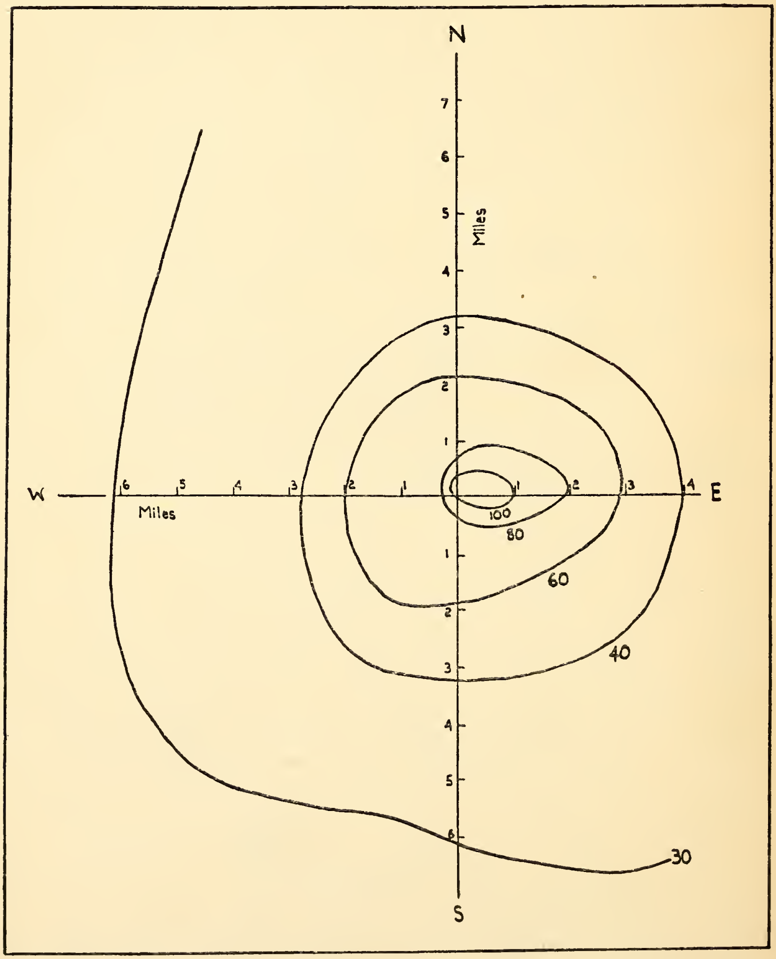


Fig. 22.—Composite map of pollution expressed as a percentage of that in the centre of a town.

Thus in the Glasgow district (Fig. 23) the area of maximum pollution is a long narrow ellipse which follows the valley of the Clyde, but there is a subsidiary centre in the south.

The detailed distribution of pollution in the neighbourhood of a town depends on the local sources. It could probably be

worked out roughly by a study of these, or a rapid survey could be made by means of petri dishes and a portable apparatus for measuring suspended impurity (Anon., 1944). For a description of a planned survey of atmospheric pollution in and around Leicester, see A. R. Meetham (1948).

The concentration of smoke particles in the air (as distinct from the deposited particles) increases from 7 mg./100 cubic

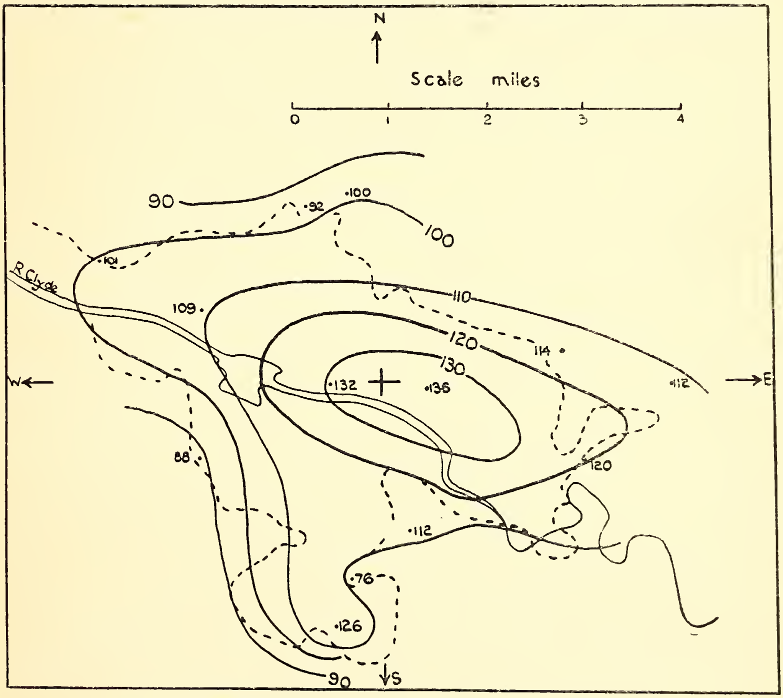


Fig. 23.—Distribution of pollution in Glasgow.

metres in Leicester (population 260,000) to 84 mg. in London (population 8,000,000), but local conditions have much influence. Thus Cardiff, where low-volatile coal is burnt in domestic grates instead of the usual bituminous coal, is a very clean city.

The smoke from a large town affects the country for a considerable distance to leeward. I estimated that even in the large area of Greater London only about one-third of the smoke produced is deposited within the urban area; the remaining two-thirds is carried into the countryside or even out to sea. London smoke is noticeable as far away as Norwich. The

proportion of the smoke of smaller towns carried into the country is naturally much larger, probably about nine-tenths. An analysis of the composition of the deposited pollution in different localities showed that the ash and carbonaceous particles are largely deposited near their sources, and the soluble material is mostly carried into the country.

The amount of pollution held in suspension in the air is also of great interest. "Suspended impurity" is measured by drawing a known quantity of air through filter paper and comparing the resulting stain with a standard set of stains; measurements are made automatically every hour at a few places in Britain. The results at Kew Observatory, Richmond, were discussed by H. L. Wright (1932).

Town air contains a very large number of microscopic smoke particles—as many as 870,000 per cubic inch (53,000 per cubic centimetre) have been found during a dense fog in London. The average number at Kew Observatory in 1928–30 was 12,500 per cubic inch (760 per cc.), but the annual variation is very great, ranging from 39,000 per cubic inch in December to only 1,000 in June. The number was three times as great with winds from east (*i.e.* from London) than from other directions.

A town fog brings out the full unpleasantness of suspended atmospheric pollution. A clean white country fog, though it reduces visibility and is damp, is not otherwise unpleasant. In a large town the same fog is a dirty brown, often with an acrid taste and smell, and this is entirely due to the admixture of atmospheric impurities. The latter include a number of hygroscopic nuclei on which the water vapour condenses. This condensation increases the weight of these particles, which tend to fall out of the air. G. M. B. Dobson (1948) points out that for this reason a town fog becomes much cleaner during the night, when the outpouring of smoke into the air is least, but becomes dirty again as soon as fires are lit in the morning. The fog droplets also dissolve the sulphur dioxide present in polluted air, forming sulphurous acid which gradually oxidises into sulphuric acid. This tends to prevent the fog droplets from evaporating when the relative humidity falls, and Dobson considers that this may be the reason why fog often persists longer in towns than in the country.

The *diurnal variation* of suspended impurity is of interest in connection with the ventilation of buildings. H. L. Wright's

figures for Kew Observatory are shown in Fig. 24 (average for 1928–30). This shows that the air is cleanest about 3–4 a.m. and 2–3 p.m., and twice as dirty about 9 a.m. and 8 p.m. The diurnal cycle shows an interesting parallel with the cycle of human activity. In the early morning domestic fires are out and factory furnaces are banked. After 6 a.m. the fires are lit or stoked with great production of smoke. Following on this morning activity the fires burn more cleanly, but the greatest factor in the afternoon minimum is probably the greater turbulence, resulting in the more rapid mixing of the smoke-laden

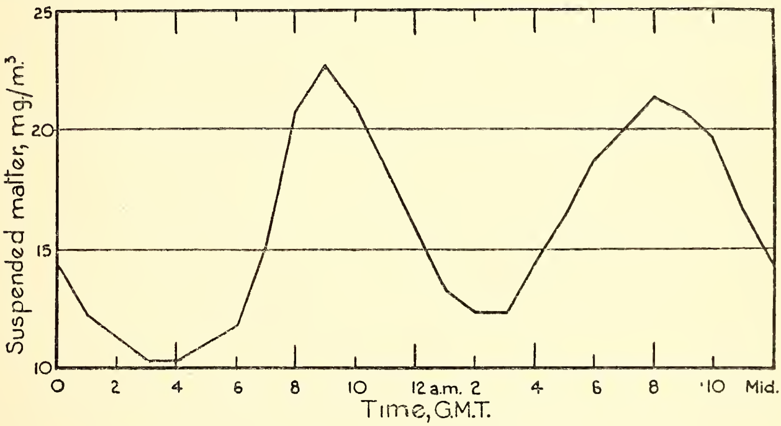


Fig. 24.—Suspended impurity at Kew Observatory.

air with cleaner air from above. This turbulence decreases during the evening and the lighting-up of home fires produces the second maximum from 7–10 p.m.

Atmospheric pollution is a serious trouble in the manufacturing areas of the United States. There is a well-known rhyme about Pittsburgh:—

"Mary had a little lamb,
Its fleece was white as snow;
She took it down to Pittsburgh,
And look at the poor thing now!"

NOTE.—A serious disaster occurred recently at Donora near Pittsburgh. Donora lies in a narrow winding industrialised valley, from which the smoke finds difficulty in escaping during periods of calm anticyclonic weather. Such a situation persisted from 26th to 30th October 1948, and was accompanied by thick persistent fog. According to a preliminary report by R. D. Fletcher (1949), near the end of this five-day period the accumulation of "smog" (a graphic portmanteau word for "smoky fog") was so stifling that hundreds of people were affected and twenty died.

In this city the steep valleys form conduits through which atmospheric pollution flows by air drainage from the numerous industrial centres in the Ohio Basin (H. F. Hebley, 1948).

Air which has travelled for a long distance over the sea is generally very clean, and on west coasts in regions of prevailing westerly winds the towns benefit from this supply of clean air. In California where, because of the cold current off-shore, there is often an increase of temperature with height up to a "ceiling" at a height of a few hundred feet, the smoke produced by the towns is not dissipated by turbulence, and pollution is a serious problem in the centres and eastern parts of these towns. The problem in Los Angeles, for example, was discussed by C. G. P. Beer and L. B. Leopold (1947). On east coasts with prevailing westerly winds the neighbourhood of the sea makes little difference in winter, but in summer sea breezes bring in cleaner air by day. The local distribution of smoke near the source and the means of minimising the nuisance were described in Chapter II (p. 92).

## MINIMISING ATMOSPHERIC POLLUTION

Efficient methods of combustion can do a great deal to decrease the emission of smoke into the air, but they cannot eliminate it altogether. They are less successful with the emission of gaseous impurities such as sulphur dioxide which escape with the flue gases, though in some large plants such as the Battersea Power Station about 90 per cent. of the sulphur dioxide is removed from the effluent gases by washing.

The problem of control of pollution is a perennial one, but the most thorough investigation arose in connection with claims for damage to crops in the State of Washington by gases from the smelter works at Trail in British Columbia, seven miles from the boundary in a deep, narrow valley. The results of this investigation are described by E. W. Hewson (1945). It was found that in light winds along the valley the gases, which are initially about 70° F. warmer than the surrounding air, rise to a height of about 500 feet above the chimney stacks, and then flow along the valley in a broad ribbon which is initially about 200 feet deep. The spreading of this layer of polluted air along the sides and bottom of the valley is brought about

partly by the local circulation of air in the valley and partly by eddy diffusion due to turbulence in the air.

The local circulation depends on the local topography, and was investigated by aircraft and kite-balloon as well as by observations on the ground, the sulphur dioxide itself being used as an indicator. The turbulence was measured by a special instrument devised for the purpose, described in detail by Hewson. The effect of turbulence on a layer of gases emitted at a considerable height above the ground shows a marked diurnal variation. In the early morning the temperature near the ground increases upwards (inversion) and the air is stable. Consequently the gases remain at about the height of emission, where they spread out to form a definite layer. Shortly after sunrise the ground begins to warm up and a turbulent layer forms near the ground, destroying the inversion. As soon as the top of this turbulent layer reaches the level of gases the latter spread rapidly downwards to the ground. This is the most dangerous period. An hour or two later the inversion is completely destroyed, the turbulent layer extends well above the level of emission of gases, and the gas layer is dissipated upwards and quickly disappears.

The control measures adopted depend largely on the wind direction and speed and the degree of turbulence. When the wind is more than 5 m.p.h. and is blowing away from the agricultural area, emission of gases can do no harm. When the wind is less than 5 m.p.h. or is blowing towards the agricultural area, emission is only reasonably safe when the turbulence at the level of emission is sufficiently great to dilute the gases with clean air and so lower the concentration before they have travelled far enough to do damage. These control measures are checked by actual observations of the concentration of $SO_2$ at a point some distance down the valley from Trail.

Hewson points out that similar measures of control could be adopted to regulate the emission of gases in level country, with the additional advantage that emission could be planned in advance in accordance with the weather forecasts, which is not practicable at Trail because of the mountainous nature of the country.

When the emission takes place at or near ground level, as in the cleaning of sewage plants, the first stage in the dissipation is omitted. So long as there is an inversion of temperature the

gases will tend to drift over the ground at a low level, but when the lower air warms up the turbulence will quickly carry them upwards. Gardeners in residential districts who wish to remain popular with their neighbours will also do well to consider whether or not there is an inversion before lighting a smoky bonfire.

### SALT NUCLEI

In addition to smoke particles, dust, organic debris, etc., there are present in the air ultra-microscopic particles which are hygroscopic and act as nuclei of condensation for water vapour. Some of these originate as products of combustion, but many of them are believed to be molecules of salt derived from the evaporation of sea spray. These are especially numerous in coastal districts and, during gales with the wind on-shore, salt particles may be carried far inland. They probably account for some chemical corrosion and have also been known to interfere with electrical transmission by forming a conducting layer over the surface of insulators. A notable case occurred in October 1927, following a south-westerly gale (Anon., 1927). This carried a considerable amount of salt spray inland. In South Wales the salt solution immediately caused shorting and failure of transmission. At the time, however, the air was dry, and the spray soon evaporated, leaving salt crystals. These were plastered over the insulators of power lines in the Midlands, but the salt was too dry to be a good conductor, and there were no transmission failures there until a day later, when the humidity rose nearly to saturation point.

# CHAPTER X

## CLIMATIC ACCIDENTS

IN this chapter we discuss briefly the nature and distribution of some of the more violent atmospheric phenomena. These may be listed as follows:—

(1) Exceptionally heavy rains.
(2) Floods.
(3) Hail.
(4) Snow.
(5) Ice storms.
(6) Lightning.
(7) Tornadoes and squalls.
(8) Hurricanes, typhoons and tropical cyclones.

Frosts were dealt with in Chapter II and exceptionally high temperatures in Chapter VIII.

### EXCEPTIONALLY HEAVY RAINS

In the design of buildings, roads, airfields, etc., it is essential to take account of the greatest rainfall to be expected in a short period. The heaviest bursts of rain last only a few minutes; as the time interval considered grows longer the average intensity falls off. The heaviest rainfalls which have been recorded anywhere in the world in different periods of time are:—

| Time Minutes | Amount inches | Rate in./hr. | Place | Time Hours | Amount inches | Rate in./hr. | Place |
|---|---|---|---|---|---|---|---|
| 1 | 1·02 | 61·0 | California | 3 | 16 | 5·3 | Pennsylvania |
| 5 | 2·28 | 27·4 | Panama | 4 | 17 | 4·3 | Queensland |
| 14 | 3·9 | 16·7 | Roumania | 24 | 46 | 1·9 | Philippines |
| 60 | 10·0 | 10·0 | New South Wales | 2 days | 66 | 1·4 | Formosa |
| 60 | 11·5 | 11·5 | California | 4 days | 102 | 1·1 | India |

These may be termed "freak rains"; the odds against encountering a fall of these amounts in any particular place in any one year are so great (probably millions to one) that the risk need not be taken into account. We are concerned here with falls that may reasonably be allowed for.

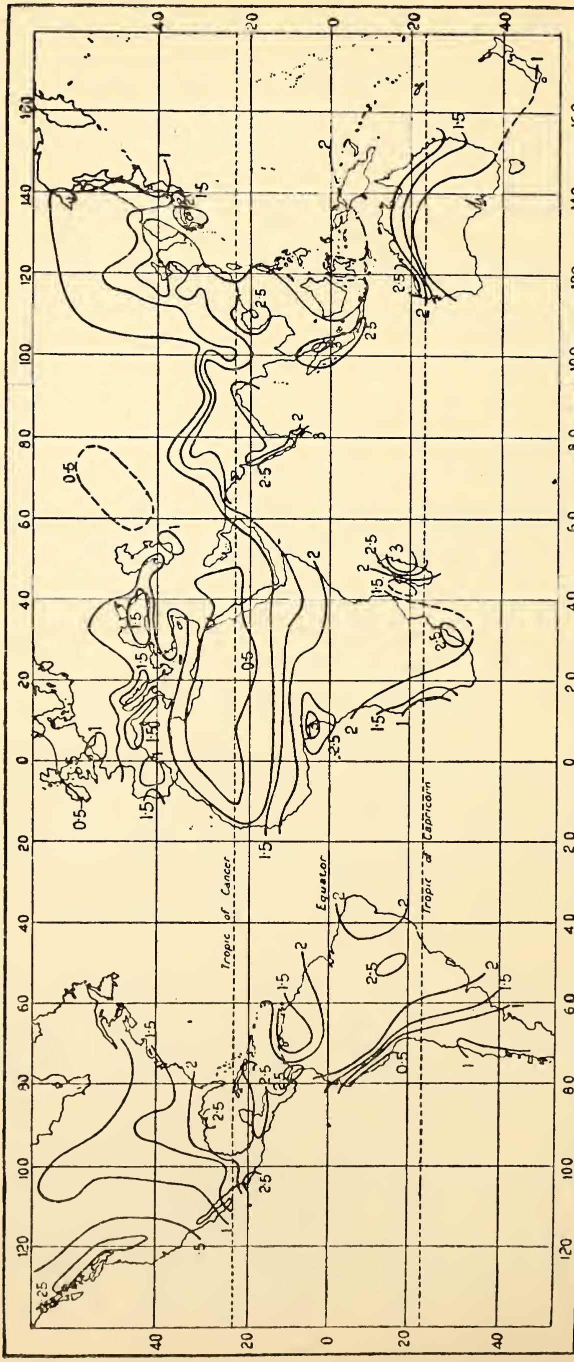


Fig. 25.—Maximum rainfall in one hour (inches) expected once in two years.

Fig. 25 shows the maximum rainfall to be expected in one hour once in two years. This map is based on a number of actual records of autographic gauges and on statistical relations of the rainfall in one hour to that in a day, and to the mean annual number of thunderstorms. The construction of the map was described by C. E. P. Brooks and N. Carruthers (1946), who also give a map of the maximum to be expected in two hours. Fig. 25 shows that once in two years a fall of 2·5 inches or more in an hour may be expected at places in the wetter parts of Central America, around New Orleans, the Cameroons and coast of Nigeria, Natal, eastern Madagascar, the west coast of India, Malaya and Java, around the Gulf of Tongking, and north-west Australia; locally the fall may exceed 3 inches. As an indication of the intensity of such a fall it may be remarked that it has probably been exceeded only once anywhere in the British Isles since records began.

For various purposes we require to know the maximum fall to be expected in different intervals of time in different numbers of years. The following table gives the highest falls to be expected at any one place in different periods in the British Isles (based on E. G. Bilham, 1936) and the Gulf Coast of U.S.A. (based on D. L. Yarnell, 1935):—

TABLE 23.—Heaviest rain in different periods, inches.

| Once in years | Britain | | | | | Gulf Coast of U.S.A. | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 5 mins. | 30 mins. | 1 hour | 2 hours | 24 hours | 5 mins. | 30 mins. | 1 hour | 2 hours | 24 hours |
| 2 | 0·24 | 0·45 | 0·6 | 0·7 | 1·6 | 0·55 | 1·8 | 2·4 | 3·2 | 5·4 |
| 5 | 0·36 | 0·62 | 0·8 | 1·0 | 2·0 | 0·60 | 2·2 | 2·9 | 4·0 | 6·4 |
| 10 | 0·45 | 0·77 | 1·0 | 1·2 | 2·5 | 0·66 | 2·4 | 3·2 | 4·5 | 7·8 |
| 25 | 0·62 | 1·02 | 1·3 | 1·6 | 3·2 | 0·77 | 2·7 | 3·7 | 5·3 | 9·6 |
| 50 | 0·77 | 1·25 | 1·6 | 1·9 | 4·0 | 0·87 | 3·0 | 4·1 | 6·0 | 10·6 |
| 100 | 0·92 | 1·50 | 2·0 | 2·4 | 4·8 | 1·00 | 3·3 | 4·6 | 6·6 | 14·0 |

In Java the highest falls in forty-six years were (inches): 5 minutes, 0·63; 30 minutes, 2·3; 1 hour, 3·7; 2 hours, 5·6; 24 hours, 11·4.

For Britain E. G. Bilham (1936) gives the expression:—

$$n = 1{\cdot}25t(r + {\cdot}1)^{-3{\cdot}55}$$

where $n$ is the number of falls in ten years equal to or exceeding $r$ inches in $t$ hours. This may be written

$$R=(\cdot 125YH)^{0\cdot 282}-0\cdot 1$$

where $R$ is the maximum rainfall to be expected in $H$ hours once in $Y$ years. For other parts of the world, especially the U.S.A., other formulæ have been devised. One of the simplest, given by R. W. Powell (M. M. Bernard, 1932) takes the form

$$R=c(YH)^{\frac{1}{4}}$$

*i.e.* the maximum rainfall to be expected in $H$ hours once in $Y$ years is proportional to the fourth root of the product of the number of years by the number of hours. In Fig. 25 $Y=2$ and $H=1$, so that the maximum rainfall to be expected in $H$ hours once in $Y$ years is 0·7 times the value read off the chart, multiplied by the product of the square roots of the number of years and the number of hours. Note that the latter may be a fraction, *i.e.* 30 minutes is ½ hour.

It is simplest, however, to consider the number of years and the time interval separately. For the former Brooks and Carruthers (1946) give the simple approximation that the maximum to be expected in $Y$ years is $(1+\log Y)$ times the average maximum in one year. If $Y$ is 2, $(1+\log Y)$ is 1·3; if $Y$ is 10, $(1+\log Y)$ is 2, and so on. This rule gave good results. In Fig. 25 $Y$ is 2, so that the factors by which figures read off the chart are to be multiplied to give the maximum rainfall in an hour expected in $Y$ years are:—

| $Y$ | 1 | 2 | 5 | 10 | 25 | 50 | 100 |
|---|---|---|---|---|---|---|---|
| Factor | 0·77 | 1·0 | 1·3 | 1·55 | 1·85 | 2·1 | 2·3 |

Correction to other intervals of time is more difficult, since no simple expression seems to cover adequately the whole range of time from a few minutes to twenty-four hours.

For rainfalls in short periods of, say, five minutes to one hour, a favourite expression with engineers takes the form

$$R=aT/(T+b)$$

where $R$ is the rainfall (inches) in $T$ minutes; $a$ and $b$ are constants, but the values assigned to them vary widely. In Britain and similar temperate climates a safe upper limit is

given by taking $a$ as 7/6 of the value for one hour read off Fig. 25, and $b$ as 10. In tropical and sub-tropical regions the heaviest falls are more persistent, so that the ratio of the maximum fall in five minutes to that in one hour is smaller. Upper limits to maxima in these regions are given by taking $a$ as 4/3 of the value read off Fig. 25 and $b$ as 20.

For periods of one to twelve hours Brooks and Carruthers (1946) found that a good approximation is given by the rule that the maximum to be expected in $N$ hours is $(1+\log N)$ times the maximum to be expected in one hour. The form $R=aN/(N+1)$ adopted by B. D. Richards (1944) gives identical values for durations of one to four hours, but lower values for durations of six and twelve hours. The ratios given by these two expressions are shown in the following table:—

| Time, hours . | 1 | 2 | 4 | 6 | 12 |
|---|---|---|---|---|---|
| *Ratio* | | | | | |
| $1+\log N$ . | 1·0 | 1·3 | 1·6 | 1·8 | 2·1 |
| $2N/(N+1)$ . | 1·0 | 1·33 | 1·6 | 1·7 | 1·85 |

The maximum in a day, expected once in two years, is shown in Fig. 26. For conversion to the maximum in some number of years other than two, the factors given on p. 204 apply. It is to be remarked that Fig. 26 refers to the maximum rainfall in the "rainfall day," generally from 9 a.m. to 9 a.m. next day, and not to the maximum in any period of twenty-four hours. As, however, the maxima generally come in thunderstorms, which are most severe in the afternoon and evening, the difference is not great.

The most intense falls are generally confined to relatively small areas. In severe thunderstorms in the British Isles the average duration at any place is about two hours, and the average area over which rain is falling at the same moment at the rate of an inch or more in an hour is about 20 square miles (50 square miles in exceptional storms), while the area over which rain is falling at the rate of 2 inches per hour ranges from less than one to three square miles. As the storms move over the country the actual area of heavy rain during the day is much greater than this. Thundery rain of less intensity generally falls over much wider areas. In the tropics the areas of very heavy rains are probably larger, but there are few data.

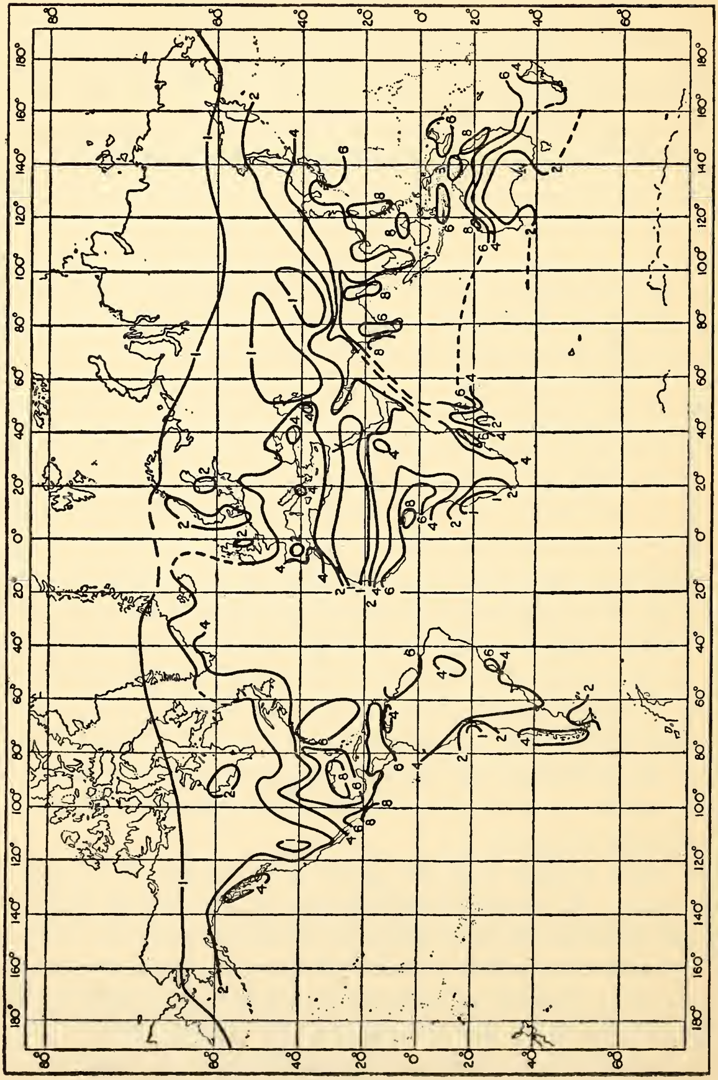

Fig. 26.—Maximum rainfall in one day (inches) expected once in two years.

J. Glasspoole (1930) quotes the following areas for typically severe storms:—

TABLE 24.—Areas of rainstorms.

| | Rainfall exceeding (inches) | | | | | |
|---|---|---|---|---|---|---|
| | 6 | 5 | 4 | 3 | 2 | 1 |
| | sq. mls. | sq. mls. | sq. mls. | sq. mls. | sq. mls. | sq. mls. |
| London, 16th June 1917 . . | — | — | 0·4 | 4·4 | 20 | 51 |
| Angerton, Northumberland, 7th September 1898 . . . | 3 | 11 | 27 | 50 | — | — |

A number of figures for different parts of the world, for storms lasting a few days, are given by B. D. Richards (1944), for areas up to 6,000 square miles. His figures for eastern U.S.A., West Australia and Central India for storms lasting on the average four days show that, if the square mile of maximum rainfall is taken as 100 then the averages over larger areas centred on this are:—

| | | | | | | |
|---|---|---|---|---|---|---|
| Area in sq. miles | 1 | 500 | 1,000 | 2,000 | 4,000 | 6,000 |
| Rainfall intensity | 100 | 89 | 85 | 79 | 71 | 67 |

In Britain, according to figures given me by J. Glasspoole, the intensity falls off more rapidly with increasing area, being 72 for an area of 500 square miles and 51 for 3,000 square miles.

## FLOODS

The risk of flooding by heavy rain depends on the nature of the ground as well as the amount of rain. A valley with a small catchment area is more liable to sudden floods than a river system with a large basin, because the areas of most intense rain are local, and usually affect only a part of a large basin; moreover, in the latter rain falling in different localities reaches the main river at different times. For these reasons the maximum discharge to be expected from river basins of different areas (but otherwise similar) is proportional, not to the area, but to the area raised to some power less than one. The maximum flow $Q$ may be put in the form $Q=cA^{\rho}R$ where $A$ is the area and $R$ the maximum rainfall. Estimates of $\rho$ vary from 2/3 to

5/6; 3/4 may be taken as an average figure. The constant *c* depends on the steepness, permeability, etc., of the basin.

The risk of flooding cannot be calculated directly from the probable maximum rainfall, because the loss by percolation into the ground, ponding, evaporation and absorption by vegetation is very variable. The actual run-off from a single heavy fall may vary from about 10 per cent. to nearly 100 per cent. of the fall; it probably averages somewhat less than 50 per cent. Fortunately in summer, when the heaviest thunderstorms occur, the ground is generally most able to absorb a large proportion of the water. The floods most destructive to property occur in the larger river basins, such as the Mississippi, but these rise slowly and in the Mississippi floods, thanks to the flood-warning system of the U.S. Weather Bureau, there is rarely much loss of life. The modern flood forecasting service was described by M. Bernard (1948). Smaller rivers, especially in hilly country, rise much more rapidly and are more liable to cause loss of life. The Ohio is especially dangerous. According to J. B. Kincer (1937), in the years 1903–35 the damage to property by floods in the U.S.A. amounted to about 550 million pounds (excluding soil erosion) and the loss of life to about 3,000. For details of some great floods in the United States see pp. 121, 123.

In any particular situation the heights of floods in the past are the best guide, *provided that the bed of the river has not changed.* Some rivers are unstable, frequently changing the shape of their beds, and in these flood prediction is very difficult. The embanking of rivers, building of bridges, locks and other obstructions may profoundly alter the flow not only locally, but for some distance up and downstream. Any narrowing or obstruction raises the flood-level upstream by an amount which may exceed 10 feet and lowers it downstream. Low bridges are especially dangerous because they may stop ice, floating trees and other debris and so build up an effective dam. Local deepening of the river bed by dredging is of little use as the level is soon restored by the deposit of silt.

The height of the greatest floods in the past can be found from natural marks on the banks, marks made on buildings or bridges to record the height, readings of flood gauges and the memory of the "oldest inhabitant." Natural marks are not always safe guides because for one thing capillary action may

raise the water level considerably inside porous stones, and for another, because they record the heights of wave-tops and not of the general flood level. A swift current piles up water against the piers of bridges and other obstructions and produces a local rise which does not extend to the banks.

The memory of the "oldest inhabitant" is not to be neglected, when no other information is available. A warning is supplied by the building of a bridge in Scotland subsequently destroyed by flood. There were no written records, and the statements by local residents of the height to which the mountain stream had risen in the past seemed so incredible that the engineers dismissed them. Had they been believed the bridge might have been saved.

The best basis for estimating the probable height of future floods is in actual records, either of the depth of water or of the volume of flow. Owing to the irregular shape of most river beds the height is not proportional to the volume, but by measuring a cross-section of the river bed the volume corresponding with any given level can be found; it is the sectional area of the river bed below that level multiplied by the average speed of flow. It has been found that the frequency of floods exceeding different volumes of flow in the Thames at Teddington in a given number of years is given by the expression

$$\log F = 19{\cdot}4 - 4{\cdot}88 \log f$$

where $F$ is the frequency per cent. and $f$ is the flow in millions of gallons. There seems no reason why a similar rule (with different constants) should not apply to other rivers. Thus, if the highest flood level in a given period is known, this can be converted to the corresponding volume, and so to the highest level to be expected in another period of years. Moreover, by converting height to volume, the effect of narrowing or obstructing the river bed on the water level can also be calculated. The fact that narrowing the bed makes the river flow somewhat faster will probably not make a great deal of difference, but in any case can be written down as a safety margin.

Measurements of rainfall are often available for long periods. If a record of river flow is available for a few years it may be possible to establish a relation between rainfall and river flow, from which the flow which probably followed the heaviest rainfall experienced can be calculated.

Floods can be minimised to some extent by providing easier run-off for the water (widening, deepening or straightening the channel), by building dykes or levees to control the water within bounds, or by spreading the peak of the flood over a longer period by constructing reservoirs to hold up the flood water. Afforestation of steep-sided valleys also serves to check the rate of run-off. Ground cultivated or covered by vegetation can absorb from a half to two-thirds of the rain falling on it, where the same soil, bare and uncultivated, absorbs only a quarter or less. For a detailed study of the estimation of probable flood levels see B. D. Richards (1944). An account of the problem in more general terms is given by M. Pardé (1946).

## HAIL

Storms of large hailstones are very destructive, beating down crops, smashing glasshouses and windows, killing animals and even penetrating corrugated iron roofs. Their danger to wine crops is shown by the efforts made in France and Italy since early times to avert them, first by the ringing of church bells and later by shooting cannon at the thunder clouds, neither of which had any noticeable effect (see p. 260). There is also extensive insurance against loss by hail. According to J. B. Kincer (1937) the destruction of crops in the U.S.A. in the seventeen years 1909–25 amounted to 228 million bushels of wheat, 286 million bushels of oats and nearly 360 million bushels of corn.

Hailstones vary in size from small, innocuous pellets of soft ice to solid spheres several inches in diameter. Since hailstones can only grow while being supported on violent up-currents of air they are mostly associated with severe thunderstorms. Comparable statistics from different countries are hard to obtain because of great variation in size of hailstones and also of the very local distribution. H. Lemons (1942*a*) gives a map showing the distribution of hail in the U.S.A. in which the figures vary from less than two a year in the southern, eastern and north-eastern areas to six on parts of the Pacific coast and six to eight in Wyoming, Colorado and Nebraska. But the Pacific coast hailstones are small and soft while in the Middle West they are often large and destructive. At Potter, Nebraska, on 6th July 1928, hailstones "as large as grapefruit" fell, one of which

measured 15 inches in circumference and weighed $1\frac{1}{2}$ lbs. Hail is not infrequent in Canada and does some damage to the tobacco, fruit and wheat crops. Severe hailstorms are frequent in the Transvaal, and hailstones weighing more than five ounces have been recorded, destroying tiled roofs and piercing galvanised iron. In the hailstorm of 25th December 1923 at Pretoria damage to property amounted to £80,000. Large hailstones have also been reported from Nigeria and Egypt. In Britain hailstones the size of "tennis balls" have been recorded, killing chickens and piercing corrugated iron and the fabric roofs of motor-cars. On 11th May 1945 one hailstone, "not the largest," was found to weigh $8\frac{1}{2}$ ozs. Judging by the holes made in an asbestos roof, even larger stones may have fallen in Northamptonshire in September 1935.

According to E. G. Bilham and E. F. Relf (1937), the limiting velocity of fall of spherical hailstones increases abruptly when the weight of the hailstone reaches $1\frac{1}{2}$ lbs., and that weight is therefore about the maximum possible. The plains of India suffer from storms of large hailstones, descriptions of which were collected by J. Eliot (1899) and a statistical analyses of these data supported Bilham's conclusion (C. E. P. Brooks, 1944).

The terminal velocity of a hailstone in still air depends on its size and density (*i.e.* on the amount of air included in the ice). For a specific gravity of 0·6 Bilham and Relf give the following theoretical velocities:—

TABLE 25.—Terminal velocity of hailstones.

| Diameter, inches | $\frac{1}{4}$ | $\frac{1}{2}$ | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|---|
| Weight, ozs. | 0·003 | 0·02 | 0·18 | 1·5 | 4·9 | 11·6 | 22·7 |
| Velocity, feet/second | 29 | 42 | 59 | 84 | 104 | 124 | 323 |
| m.p.h. | 20 | 29 | 40 | 57 | 71 | 91 | 220 |

When the diameter exceeds about $4\frac{1}{3}$ inches, the theoretical velocity is much higher (323 ft./sec., or 220 m.p.h. with a diameter of 5 inches), but Bilham considers that it is very doubtful whether this is ever reached in nature. But even a mass of 12 ozs. hurtling through the air at 90 m.p.h. can do considerable damage.

At places in the British Isles hail is recorded from three up to more than twenty times a year (London, Met. Office, 1923).

The larger frequencies are found in the west, but they refer almost entirely to unimportant falls of small or soft hail. Damage by hail is mostly confined to the east and Midlands, destructive storms beating down crops and breaking glass and tiles occurring at intervals of a few years. At any one place the frequency is of course less than this, and individual farms may escape altogether for decades. It is recorded that the storms of 24th June 1897 in Middlesex and Essex, in which hailstones "as large as hens' eggs" fell with violent winds, caused great distress among farmers as there had not been a bad hailstorm for some years and many of them had ceased to insure against hail. Close to the Equator hail is less frequent because even at heights of 20,000 feet or so the air is too warm for its formation. According to H. Lemons (1942*b*) hail is small and rare in tropical islands, and in the tropics generally it is more frequent and severe at high altitudes than in the lowlands. In high latitudes there is probably no true hail.

## SNOW

Heavy or continuous snow interferes with rail and road traffic. In Britain snow falls on a few days a year in the south-west, ten to fifteen days in the south-east, increasing to twenty to twenty-five days in the Midlands and forty to fifty days in the Highlands of Scotland. In colder parts of the world snow is very frequent in winter. Many falls of snow, however, are small and either melt rapidly or add little to the existing snow cover; heavy falls are rare and occur in only a small proportion of the years. Accounts of some of the worst storms in recent years in Britain are given in Chapter III (p. 100) and in the U.S.A. in Chapter IV (p. 120). For a discussion of the protection of railways from drifting snow by fences or plantations, and clearance of drifts, see W. K. Wallace (1949).

In countries with cold winters a persistent snow cover forms every year. A map of the average duration of snow cover is given in Fig. 8, but there are wide variations from year to year.

Snow on skylights interferes with the top-lighting of rooms by daylight. The loss of daylight is mainly due to the high reflectivity of a snow surface; even a very thin layer of new snow reflects about 80 per cent. of the light falling on it. From some

observations by L. C. Porter (1934) in Cleveland, U.S.A., it appears that half an inch of light fluffy snow further reduces the illumination to about 7½ per cent., 1 inch to 3 per cent., and 3 inches to only 1 per cent. of that above the snow. In the case observed by Porter, an outside illumination of 247 foot-candles was reduced to 2-foot candles by 3¼ inches of snow on a skylight.

*Glazed frost* ("*ice storm*") is described on pp. 47 and 120. Widespread glazed frost is fortunately very rare in Britain, occurring only at intervals of several years; when it does occur it completely dislocates road and even rail transport, and often telephonic and telegraphic communication as well. The damage which probably takes longest to repair is the wholesale breaking of telephone and telegraph wires and even the snapping or uprooting of whole rows of poles.

Glazed frost is also a source of trouble on overhead transmission lines of electric power systems. According to H. W. Grimmitt (1945) the most frequent cause of damage is short-circuiting and burning of the insulation. The conductors are weighed down by the ice, and when it falls off one conductor this rises abruptly and may come in contact with higher conductors. The conductors and even the supports may break under the weight of ice, especially when the wind is strong. Strong winds are rare during the actual formation of glazed frost, but may spring up afterwards, while the ice is still on the wires. Grimmitt gives a tentative map of the distribution of "ice-storms" which affect overhead transmission lines. This shows frequent occurrences in the hill country of the Pennines and South Wales, where above 1,000 feet trouble may be expected every other winter, "infrequent" damage on the eastern side of the Pennines, in North Wales, parts of the Midlands, Gloucestershire, northern Devon and Somerset, Wiltshire and Hampshire, and none elsewhere except for a small area on the North Downs of Kent. Of the twenty-eight years, 1916–43, damage was reported in thirteen years, but in five of these it was only local and slight.

## LIGHTNING

A lightning flash consists of a series of discharges of electricity following one another very quickly along the same track. Most flashes travel from one point in the cloud to another;

some travel from cloud to earth and possibly a few from earth to cloud. A lightning flash is usually branched, the branches pointing in the direction of travel, so that a discharge from cloud to earth usually reaches the ground along several channels. Near the ground a discharge from earth to cloud is concentrated in a single channel and is generally more intense. B. F. J. Schonland (1938) doubts the existence of earth-cloud flashes, but G. C. Simpson (1929) shows a photograph of flashes branching upwards. These papers by Simpson and Schonland give detailed descriptions of the complicated structure of lightning.

Because of its spectacular and terrifying nature lightning has always played a large part in popular imagination, but though the total annual loss of life and property from lightning over the world is large it is probably much smaller than that due to other climatic accidents such as floods and hurricanes. The effects of lightning may be considered under: destruction of life; destruction of property mainly by fire; interference with electric power systems.

The number of persons killed by lightning depends partly on the frequency of thunderstorms (see below) and partly on the local conditions. For example, the risk of death by lightning in a town is very much smaller than in the country, and it is greatest in hilly or sparsely wooded country. Most of the deaths occur among men or boys sheltering from rain under trees or in small outbuildings. Cattle and sheep are also killed under trees and near wire fences. The most complete statistics available were provided by the Metropolitan Insurance Co. (New York, 1948). These give the annual death-rate in the U.S.A. as about 400 or 3 per million. Nine-tenths of these occurred in places with 2,500 or fewer inhabitants, though such places contain only 40 per cent. of the total population. The death-rate was greatest in the Middle West and Gulf States, exceeding six per million in Montana, Idaho, Wyoming, North and South Dakota, Colorado, New Mexico, Arkansas, Mississippi, Alabama and Florida. It was under one per million in the Pacific coast States of Washington, Oregon and California, where thunderstorms are few and mild, and in the largely urbanised north-eastern States of New Jersey, New York, Rhode Island, Massachusetts and New Hampshire. In Great Britain the death-rate is probably well under one per million.

Lightning causes some structural damage to buildings and sometimes kills trees, but by far the greater portion of damage is due to fires initiated by lightning, especially forest fires. J. B. Kincer (1937) estimated the loss in the U.S.A. from fires caused by lightning as 12,000,000 dollars a year. A very costly fire was started by lightning striking a large oil tank. In forest regions the risk is greatest when thunderstorms follow a long period of fine weather during which the surface of vegetable debris becomes very dry and tinder-like. Warnings of such conditions are given by the U.S. Weather Bureau and a watch is kept. Lightning striking the wires of an overhead electric transmission service causes sudden surges of current which break down the insulation of the wires and sometimes cause transformer failures. Protection from lightning is discussed in Chapter XII.

Lightning flashes between one part of the cloud and another do no damage, and we are interested only in the frequency of cloud-earth flashes. Adequate statistics of these are available for only a very few places. R. H. Golde (1945) quotes various estimates which range from 1·5 to 9·5 flashes per square mile per annum. He estimates the most probable figure for Britain as six cloud-earth flashes per square mile per annum. The average annual number of thunderstorms ("isokeraunic level") is about twelve, and this gives us the rough rule that number of cloud-earth flashes per square mile is half number of thunderstorms in the vicinity. The same rule is adopted in the U.S.A. (R. H. Golde, 1946).

The ratio must also depend on the severity of the thunderstorms. These are most severe over inland areas, and on the north-west and west coasts of Europe and North America they are relatively mild and innocuous.

In the tropics thunderstorms give the impression of being more severe, but owing to the greater height of the clouds a much greater proportion of the flashes are cloud to cloud and correspondingly fewer are cloud to earth. Exact figures are not available, but the percentage of flashes reaching the earth in tropical regions may be a half or less of that in temperate regions. J. A. Chalmers (1941) shows that the higher the dew point of the air (*i.e.* the temperature at which water is condensed out of the atmosphere), the more probable is a lightning flash within the cloud in comparison with one to earth, the ratio being

roughly proportional to the dew point in ° C. On the other hand, the total number of flashes per storm is greater in tropical than in temperate storms. Nevertheless, one hears comparatively little about thunderstorm damage in tropical regions, and provisionally the number of cloud-earth flashes per square mile in the tropics may be taken as one-third of the number of thunderstorms.

The frequency of cloud-earth flashes probably increases with the height of the ground, but it depends very much on the nature of the surface. Towers are well known to be struck more frequently than surrounding flat ground. In U.S.A., with twenty-five to forty-five thunderstorms a year, the number of strokes on buildings up to 500 feet high increases linearly at the rate of 0·004 $H$ per annum, where $H$ is the height in feet. Above 500 feet the frequency increases more rapidly, and the Empire State Building, 1,250 feet high, was struck sixty-eight times in three years (New York, Inst. Radio Engrs., 1943). Mountains high enough to extend into the thunderclouds are very frequently struck, but the voltage of the strokes is small and they are less dangerous than flashes to low ground. According to C. F. Brooks (1935) all the superstructures, radio electric recording instruments and telephones of Mount Washington Observatory flicker with brush discharge during thunderstorms, but although the slopes are bare there are no records of death by lightning.

The annual frequency of thunderstorms was mapped by C. E. P. Brooks (1925). On the basis of this chart and of the data given above a sketch map of the probable frequency of lightning flashes to earth has been constructed (Fig. 27). This gives the estimated number of flashes per square mile per year, but in any locality there are probably local variations due to nature and elevation of ground, vegetation, buildings, etc. The causes of such variations are obscure: D. Muller-Hillebrand (1937) states that there is doubtful evidence that disturbances of conductors are most frequent where the ion-content of the air is large. It has been suspected, but probably on insufficient evidence, that underground water attracts lightning. The main point is to ensure that the masts are properly earthed and this may require special precautions in dry regions.

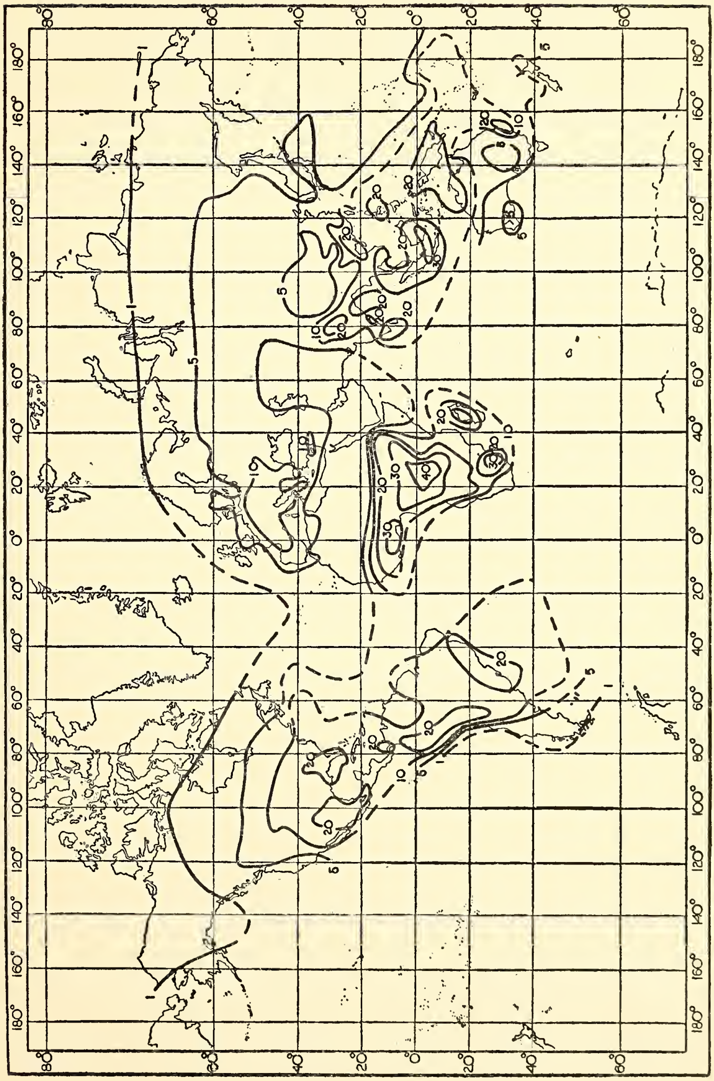

Fig. 27.—Number of lightning flashes to ground per square mile per year, estimated.

## TORNADOES AND SQUALLS

The true tornado is a whirling column of air with an average diameter of about 1,000 feet. The wind reaches very high speeds; these have never been accurately measured, since no instrument can stand up to them, but estimates from the weight of objects lifted put the maximum speed in a severe tornado as over 300 m.p.h., and sometimes as high as 500 m.p.h. The winds often have an upward component near the centre which has been estimated to reach 100 to 200 m.p.h., so that large, heavy objects may be carried up to heights of several hundred feet and transported for considerable distances. The centrifugal force of the rotating winds causes a partial vacuum in the centre. The damage is of two kinds; the wind blows or flattens down houses and trees and carries away cars and other solid objects in its path, and the sudden reduction of pressure causes buildings to "explode". The air inside a building is not given time to adjust its pressure to that of the centre of the tornado, especially if doors and windows are closed, and there is an outward pressure on walls, windows and roofs which may amount to two or three pounds to the square inch. Walls and windows are blown outwards and roofs are lifted off. This suction effect is responsible for most of the "freak" effects of tornadoes, such as plucking chickens and stripping people of their clothes. Only the strongest and sturdiest buildings can withstand the combined effects of wind force and suction. In the tornado of 1936 at Gainesville, Ga., however, buildings with strong steel frameworks suffered only minor damage, such as shattered windows, while lighter structures were completely destroyed.

When a tornado strikes a town the damage is very great. The outstanding example is the St. Louis tornado of 27th May 1896, which swept through the town and destroyed property worth 10,000,000 dollars; 306 people were killed. J. B. Kincer (1937) states that in the years 1916–35 2,800 tornadoes were reported in the U.S.A., costing the lives of 5,224 people and damage to property amounting to 230,000,000 dollars. C. W. Brown and W. O. J. Roberts (1937) estimate the direct damage to property as 250,000,000 dollars in fifty years. A single tornado on the average devastates an area of little more than one square mile, so that the total area affected in twenty years was only

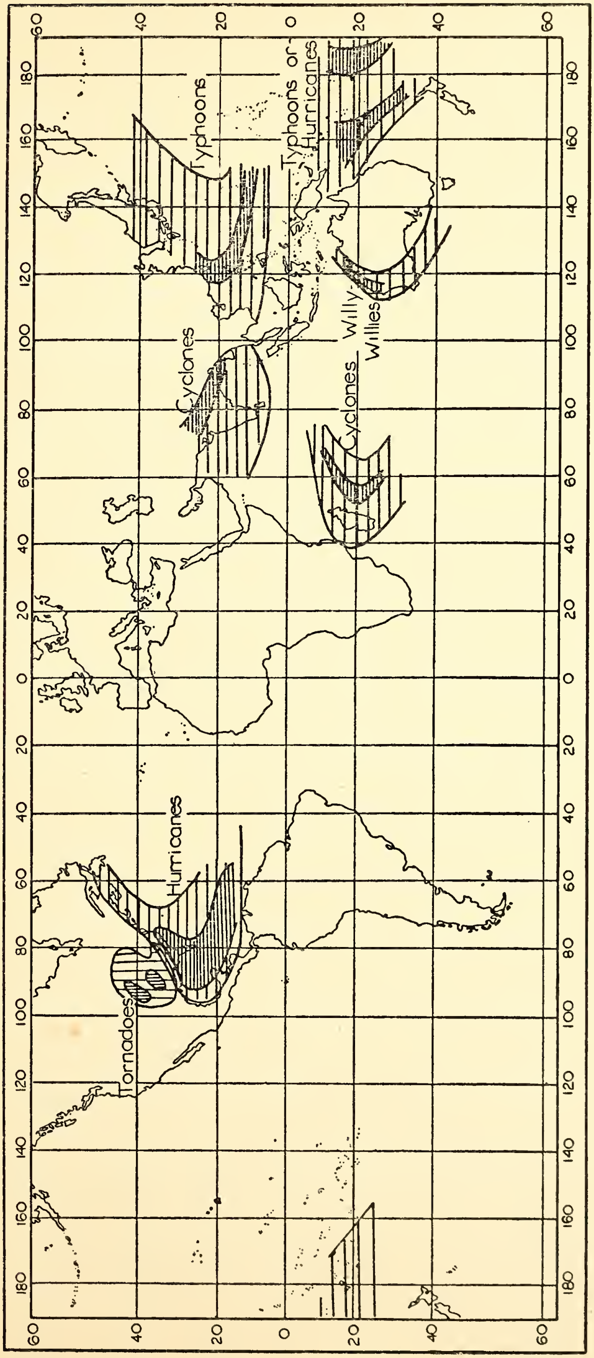


Fig. 28.—Distribution of tornadoes and tropical cyclones, hurricanes or typhoons.

about 3,000 square miles. Since the area of the U.S.A. subject to tornadoes is about 1,250,000 square miles the odds against a tornado striking any one place in any one year are at least 10,000 to one.

Tornadoes occur most frequently in the great lowland areas of the central and upper Mississippi, Ohio and lower Missouri valleys. They also occur in Georgia, North and South Carolina and the inland parts of the Gulf States; they are rare on the coasts and practically unknown west of 100° W. long. The States from which records are most frequent are: Kansas, Iowa, Texas, Arkansas, Illinois and Missouri. A generalised picture of the distribution is shown by the vertical shading in Fig. 28. A more detailed study has been made by C. W. Brown and W. O. J. Roberts (1937). They take as their unit one mile of tornado track one-tenth of a mile wide and divide the number of units observed in a county in fifty-one years into the area of the county in square miles. The answer, multiplied by 510, gives the odds against a tornado at any place in that county in any year. The figures are very irregular, partly because in the less densely peopled areas many tornadoes may go unreported, but possibly also because there may be real local differences in the frequency of tornadoes. The smallest value on Brown and Roberts' map is about five, indicating odds of about 2,600 to 1 against a tornado in any one year even in the worst areas. The risk is minute and is hardly worth bothering about. According to C. F. Brooks (1935) the insurance rate against damage by wind-storm in the eastern and middle States represents an expectation of total destruction once in over 1,200 years for dwellings or once in over thirty years for more flimsy structures, but this includes insurance against any strong wind. Many houses in the areas most affected are provided with strong cellars into which the occupants can retire on the approach of a tornado. T. A. Blair (1937) considers that the "cyclone cellar" should be completely underground and away from any other building. He adds that an automobile can generally outrun a tornado by travelling in a direction at right angles and to the left of the direction in which the tornado is advancing (*i.e.* if the tornado is moving north-east go towards the north-west).

Tornadoes of the American type occasionally occur in other parts of the temperate regions, but are less frequent and

generally less severe. In Britain the most notable was the South Wales tornado of 27th October 1913 which caused a great deal of damage along a sharply bounded track several hundred feet wide; trees were uprooted and buildings destroyed (H. Billett, 1914). Other examples were a tornado and hail-storm in Derbyshire on 12th May 1811, Dublin on 18th April 1850, Cowes on 28th September 1876, Whipsnade on 18th January 1945, and Birmingham on 4th February 1946, besides a number of minor ones which did only very local damage. These whirlwinds are generally smaller, less violent, and shorter-lived than the American variety, and though several probably occur each year somewhere in Britain the risk to any particular building is negligible. Similar visitations are sometimes reported from other parts of the world, but they are rare near the Equator. For an account of tornadoes in Europe see A. Wegener (1917).

*Squalls* differ from tornadoes or whirlwinds in the absence of rotary motion about a vertical axis. A squall is a sudden rise of wind velocity, often with a marked change of direction. Squalls are of three types:—

(1) A mass of cold air advancing along a broad front, under-cutting and violently lifting the warmer air in front of it. There is generally a brief but heavy shower of rain or hail, frequently with thunder, and a sudden drop of temperature. This type is known as a "line-squall," and is commonly associated with the passage of the "cold front" of a depression. This type of squall is most severe in middle latitudes, but it can occur also in the weaker depressions of sub-tropical regions. In Australia it is known as the "southerly burster," in the Argentine as the "Pampero" and in the southern Mediterranean as a "white squall," so-called because it brings no cloud or rain. The greatest damage is usually patchy, in strips about 30 by 100–150 yards (H. Faust, 1948). The so-called "tornadoes" of West Africa are also of this type, though local rotary motion sometimes develops.

These squalls are sometimes violent enough to do minor damage on land, but they are more dangerous to shipping because of the suddenness with which they spring up and the rapid change of wind direction. On 24th March 1878 the training ship *Eurydice* foundered during a line-squall. Because of their powerful vertical currents and great lateral extent line-squalls are dangerous to aircraft.

(2) Somewhat similar are the squall lines associated with the descent of cold air after passing over mountain ranges. The air often develops a violent rotation about a horizontal axis. Such squalls are met with in many parts of the world, but are especially frequent in the tropics; the *Sumatras* of the Malacca Strait are among the best-known examples. These squalls rarely do much damage on land, but are troublesome to shipping.

(3) Thunderstorms are sometimes accompanied by local squalls. The centre of a thunderstorm is a region of violent uprush of air, especially where hail is produced. This air is cooled and descends on the edges of the storm, mostly in front of it, where the contrast of temperature between the descending air and the undisturbed warm surface air is greatest. The down-rush is increased by the heavy rain or hail which sweeps the air along with it. The resulting squall comes up suddenly and is often strong enough to do minor damage, but the effects are usually local, limited to an area up to 5 miles long and a half mile wide.

In an example at Kano in Northern Nigeria on 12th June 1947, described by A. T. Dorrell (1947), the wind rose suddenly from 20–80 m.p.h. along a front 200–300 yards wide, and several buildings were unroofed. At the same time temperature fell instantaneously from 89°–66° F., and there was a short burst of heavy rain. Thunderstorm squalls are most frequent and severe in the transition period preceding the rainy season in sub-tropical countries.

In addition the ordinary cyclonic depressions of temperate latitudes and the cyclones, typhoons or hurricanes of tropical and sub-tropical regions (p. 225) include in their general wind circulation patches of stronger winds which to some extent resemble squalls, but are of longer duration. In temperate regions such winds are often associated with the passage of secondary depressions, and form narrow belts. A notable example occurred on 24th March 1895. A deep depression was centred over the Shetlands and a small, intense secondary depression traversed the Midlands. On the south-east of this secondary the winds exceeded gale force over a track 30–50 miles wide where a great deal of damage was done to buildings, many trees were uprooted and several people were killed. One of the minor troubles caused by squalls is the blocking of roads by trees blown across them; in severe storms this may result in a good deal of interruption to traffic.

An attempt has been made to estimate the maximum gust velocities to be expected at a height of 33 feet, once in ten years, in different parts of the world. Observations with gust-recording anemometers are rare except in Britain, parts of North America, India and a few places like Hong Kong and Singapore. Cup anemometers are more plentiful; these give the average wind (mean of gusts and lulls) which can be converted to gust velocity by using an estimate of the "gustiness factor" (p. 86). For many parts of the world only estimates based on personal impressions or accounts of damage are available. The details of the measurements or estimates are available in the Meteorological Office, London; they may be summarised as follows:—

*Exceeding 125 m.p.h.*

West coast of Iceland.
Part of the West Indies, including Porto Rico, Haiti–San Domingo, Jamaica and the eastern half of Cuba.
Coast of China around Hong Kong.
Northern end of Formosa.
Very exposed positions in eastern U.S.A.

*Exceeding 100 m.p.h.*

South and east coast of Greenland and most of Iceland.
North and west coasts of Norway as far south as 60° N.
West coasts of Scotland, Ireland, Pembroke, extreme south-west of Cornwall, Scilly Islands.
Exposed positions in interior of U.S.A., from North Dakota and Wisconsin in the north to New Mexico–Missouri in the south, and from Colorado in the west to Illinois in the east.
Coast of Florida, Georgia and Carolina.
District round Rangoon (Burma).
Coast of China from Hainan to southern tip of Japan.
Southern Sakhalin and Hokkaido.
A small coastal strip of north-west Australia between Broome and Wyndham.
South-west coast of Chile south of 50° S.

*Exceeding 80 m.p.h.*

Aleutian Islands.
Most of U.S.A. except valley regions in Rocky Mountain system and area between Alleghenies and a short distance inland from Atlantic coast.
Coast of Gulf of Mexico and all West Indies.
Coast of West Greenland to 70° N. and of East Greenland to 75° N.
The whole of the British Isles.

Norway, except where sheltered from the west.
Arctic coast of Finland and Russia.
Coast of Baltic (except Gulf of Finland), all Denmark, coastal regions of north-west Germany, Holland, Belgium.
France north of La Rochelle.
West coasts of Corsica and Sardinia, Malta and north coast of Africa from Tripoli to Morocco.
Coast of Palestine.
Bay of Bengal and neighbouring regions.
Coast of Indo-China and China from about 10°–30° N.
Southern Japan and Korea.
North-west Australia from 20° N. to Darwin.
East coast of Australia from Brisbane to Sydney and coasts of Tasmania.
Islands of Mauritius, New Hebrides, Fiji, etc.
East coast of South America from Porto Alegre to Bahia Blanca.
Coast of Chile south of 45° S., Tierra del Fuego.

Over most of the remaining parts of the world the gust velocity to be expected is about 60 m.p.h. The lowest values (below 45 m.p.h.) are found in the neighbourhood of the Equator—South America between 10° N. and 10° S., Central Africa from 5° N.–20° S., northern India under the shadow of the Himalayas, and the East Indies between about 5° N. and S.

These figures represent average open conditions. Very exposed sites on hill-tops and headlands naturally experience higher gusts; on the other hand, there are plenty of more sheltered situations, such as valleys transverse to the strongest winds, lee slopes of hills, and forest clearings, where the winds are less strong.

The highest velocity to be expected in a given period naturally depends on the length of the period, but to a much less extent than would be expected. In a single year chosen at random the highest gust to be expected is about 80 per cent. of the ten-year maximum. The hundred-year maximum is about 120 per cent. of the ten-year maximum. The maximum velocity $V_N$ to be expected in $N$ years may be related to the maximum $V_{10}$ in ten years by the approximate expression

$$V_N = V_{10}(0 \cdot 8 + 0 \cdot 2 \log N).$$

The gust velocity increases with height above the ground, but not so rapidly as the mean velocity. An expression developed

by N. Carruthers (1943) gives the following average ratios between the gust velocity at a height $H$ and that at 33 feet:—

| Height, feet . . | 10 | 20 | 33 | 50 | 60 | 80 | 100 |
|---|---|---|---|---|---|---|---|
| $V^H/V_{33}$ | | | | | | | |
| Coast . . | 0·93 | 0·97 | 1·00 | 1·03 | 1·06 | 1·07 | 1·09 |
| Inland . . | 0·97 | 0·98 | 1·00 | 1·02 | 1·03 | 1·04 | 1·05 |

The "roughness" of the ground affects the vertical variation of gust velocity. If the ground to windward of a building is occupied by shrubs, small trees, fences and similar obstacles, the speed near the ground is decreased, but that at roof height of average buildings may be increased compared with more open situations.

## TROPICAL CYCLONES, TYPHOONS, HURRICANES

The "tropical cyclone" is found between about 5° and 30° latitude, on the western sides of the Pacific, Indian and North Atlantic Oceans, in the Bay of Bengal and off north-west Australia. It does not occur in the South Atlantic. The winds blow round, and slightly towards, a central area of low pressure (the "eye" of the storm), and may reach speeds up to 180 m.p.h. At San Juan, Porto Rico, in 1928 the wind had reached this speed when the anemometer blew away, and it continued to increase in strength for some time afterwards. Winds of 125–140 m.p.h. have been recorded in a number of hurricanes and typhoons. The passage of a tropical cyclone is accompanied by heavy rain and very rough seas. In the northern hemisphere the winds blow round the centre in the opposite direction to the hands of a clock (anti-clockwise rotation). On the right of the track along which the cyclone is moving the speed at which the centre is advancing is added to the speed of rotation, so that the strongest winds are found in this sector. These winds drive before them a great mass of water, which strikes the coast as a storm wave, and may be 40 feet above the general level of the sea. When the storm wave comes at high tide it often does more damage than the wind and rain. In the southern hemisphere the winds blow clockwise about the centre and are strongest to the left of the track.

The regions in which tropical cyclones are found are indicated by horizontal shading in Fig. 28. Light shading shows regions

where visitations are rare (at any individual place only once in many decades); heavy shading indicates more frequent storms. Cyclones have a variety of names. In the Arabian Sea, Bay of Bengal and South Indian Ocean they are known as "cyclones," and in north-west Australia they are "willy-willies." In the West Indies, Gulf of Mexico and coast of Florida, and in the South Pacific they are termed "hurricanes." In the China Sea they are "typhoons" and in the Philippines "baguios," but all these names refer to the same phenomenon.

Cyclones generally originate over the ocean in about latitude 5–10° N. or S. At first they move eastwards with a trend away from the Equator, which increases with increasing latitude. In a latitude which varies with the season from 15°–25° they "recurve" and turn westwards, travelling north-west in the northern hemisphere and south-west in the southern hemisphere. The general lines of the tracks are shown by the shaded areas of Fig. 28. Some cyclones, however, follow unusual tracks, and they may not recurve at all. Eventually a cyclone either strikes land (when it usually breaks up quickly with torrential rain), dies out over the ocean, or passes into temperate latitudes, where it loses the character of a tropical storm.

Statistics of tropical storms are not complete, as some storms have undoubtedly passed unrecorded, especially in the South Pacific. The following table shows the number observed in each month, corrected to a period of fifty years to make the different regions comparable.

TABLE 26.—Number of Tropical Cyclones in Fifty Years.

| | Jan. | Feb. | Mar. | April | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. | Year |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| West Indies . | — | — | — | — | — | 15 | 18 | 47 | 82 | 66 | 11 | 3 | 242 |
| Arabian Sea . | 1 | — | — | 2 | 6 | 7 | 2 | — | 1 | 7 | 8 | 2 | 36 |
| Bay of Bengal . | — | — | — | 6 | 12 | 3 | 5 | 1 | 8 | 14 | 15 | 6 | 70 |
| China Sea and Western N. Pacific . . | 59 | 33 | 35 | 27 | 63 | 65 | 173 | 177 | 212 | 183 | 100 | 65 | 1192 |
| Eastern North Pacific . . | — | — | — | — | 3 | 29 | 37 | 39 | 89 | 45 | 5 | 3 | 250 |
| S. Indian Ocean | 66 | 84 | 61 | 28 | 9 | — | — | — | — | 3 | 12 | 39 | 302 |
| N. W. Australia | 11 | 7 | 8 | 3 | — | — | ½ | — | ½ | ½ | 1 | 5 | 35½ |
| Queensland . | 29 | 23 | 27 | 12 | 5 | 7 | 6 | — | 4 | 3 | 2 | 8 | 126 |
| South Pacific 160° E.–140° W. | 22 | 16 | 21 | 6 | 1 | 1 | ½ | ½ | 1 | 1 | 2 | 11 | 83 |

The figures for the South Pacific are based on records for the period 1789–1924, and are certainly too low.

Only about half or one-third of these storms are classed as severe; some of them bring nothing worse than strong winds. The tracks of the majority lie entirely over the oceans, and affect only a few small islands at most. For example, in the West Indies the average annual number of hurricanes reported is nearly five, but the average frequency of destructive hurricanes is less than one a year.

When a severe storm does strike a populous coast or island the damage is very great. J. B. Kincer (1937) estimated the damage by hurricanes in the United States during the twenty years 1916–35 as very nearly 386,000,000 dollars. I. R. Tannehill (1944) gives the damage to property in the United States during the period 1917–41 as about 500,000,000 dollars, but states that more than half of this occurred in the New England hurricane of September 1938. He puts the loss of human life during the same period as about 4,200 in the United States, but above 10,000 if the West Indies, Central America and Mexico are included.

De Monts (1936) considers that the cyclones of the South Indian Ocean are on the average much less severe than those of the West Indies region, the maximum wind speed averaging only two-thirds as great. In the south-eastern U.S.A. the highest waves are 30 feet above the general sea-level, in Reunion Island (21° S., 56° E.) rarely as much as 15 feet. Since the destructive power of a wave is proportional to the square of its height, the damage by waves is only a quarter as great at Reunion as in the U.S.A. On the other hand, the cyclone rainfall is generally greater in the South Indian Ocean than in the Gulf States. References to some of the worst disasters in the West Indies, south-eastern U.S.A., India, China and Japan are given on pages 124, 127, 133 and 137.

The diameter of a tropical cyclone is small near its origin, averaging 25–50 miles, but as it moves into higher latitudes it expands to an average diameter of 500 miles. The central ring of hurricane winds surrounding the "eye" is much smaller, however, probably averaging less than 100 miles. According to the Admiralty Weather Manual (London, 1938, p. 376) the average velocity 35 miles from the centre exceeds 75 m.p.h.; 50 miles from the centre it is 70 m.p.h., decreasing to 30 m.p.h. at 150–200 miles. For more severe cyclones these figures must be increased proportionally. The average width of the belt of

destruction is about 100 miles. The hurricane tracks in a region such as the West Indies are spread over a belt which has a width of the order of 1,500 miles, so that any cyclone will bring hurricane winds over less than one-fifteenth of the belt. Moreover, all cyclones do not traverse the whole length of the belt; some form and others die out within the region. Thus an average frequency of five cyclones a year in a belt 1,500 miles wide is equivalent to only one in about five years at any particular spot. Further, only about one in three of these cyclones is severe, so that the incidence of catastrophic storms is further reduced to one in about fifteen years. The risk is greatest in the centre of the heavily shaded belts and decreases towards the edges.

From some data given by I. R. Tannehill (1944) for the years 1879–1943, the average interval in years between storms of hurricane intensity per 100 miles of coast, in the south-eastern United States, is found to be:—

| | | | |
|---|---|---|---|
| Mississippi | 4 | North Carolina | 9 |
| Alabama | 5 | South Carolina | 12 |
| Texas | 7 | Louisiana | 14 |
| Georgia | 8 | Florida | 17 |

The Meteorological Services of the U.S.A., India, Philippines, etc., follow the tracks of cyclones and broadcast warnings of their approach. These warnings have saved many lives, both on land and at sea.

## DUST STORMS

One of the worst features of strong winds in arid and semi-arid regions, especially during dry periods, is the dust. In the dry years 1934 and 1935 the dust nuisance in the south-central plains of the U.S.A. became so great that this region, including parts of Colorado, Kansas, New Mexico and Oklahoma was christened the "Dust Bowl." On 11th May 1934 the dust cloud was 900 miles wide and 1,500 long; it darkened the sky over New York and Boston, while farther west snow-ploughs had to be used to clear the highways of drifted soil (C. F. Brooks, 1935). The dust lowers visibility to a few feet, interferes with road and rail transport, and abrades all surfaces against which it is blown. Automobiles travelling through a dust storm have been stripped of paint. The removal of the top soil has a disastrous effect on the fertility of the ground; in some dust

areas even weeds cannot grow and the ground is rapidly eroded. Dust storms are now regarded so seriously in the U.S.A. that they are reported annually in the *Monthly Weather Review.*

Dust storms also occur in Europe, but are only serious in the south-east, in southern Russia in particular. One such dust storm occurred on 26th–29th April 1928, when artificial light had to be used all day in eastern and central Europe, and in southern Russia the dust formed heaps like snowdrifts more than a foot deep. The worst dust storms occur in desert regions, and are typified by the *Haboobs* of the Soudan (see p. 161).

When rain falls through a dust cloud it comes down as mud. The worst mud-rains follow or accompany volcanic eruptions, but even surface dust can produce unpleasant results. When the dust originates in a desert it is frequently red, and dust from the Sahara is the basis of the occasional "blood rains" of Europe. A notable red rain fell over the southern half of England and Wales and a large part of Europe on 21st–23rd February 1903. The origin of the dust was traced back to the Sahara. Mud and sand rains make stains which are difficult to remove, but are otherwise harmless.

Most of the phenomena described in this chapter are on so large a scale, or draw on such a great store of natural energy that man can do little against them. Attempts at breaking up hailstorms are described in Chapter XII, but their success is very doubtful. The only protection against hurricane winds and tornadoes is by solid building. Protective systems against lightning (see p. 262) are good but not infallible. Probably man's most successful counter-measures against weather are special weather forecasts—warnings of heavy rain, flood, gale, thunder, snow, hail, frost, which enable precautionary measures to be taken in good time. The risk of loss by any of these climatic "accidents" is slight at any one spot in any one year, but when loss does occur it is often very heavy. The risk can be shared by insurance which is largely developed, especially in the U.S.A.

# PART III

# THE CONTROL OF CLIMATE

# CHAPTER XI

## HEATING, AIR CONDITIONING, LIGHTING, CLOTHING

A LARGE part of both the working time and the leisure of many people is spent indoors, and in order that they may maintain their efficiency the climate of the buildings in which they live, work or play must be kept within certain limits of temperature, humidity and illumination. The outdoor climate of most places, however, is outside these limits at some seasons, and the climate inside buildings must be controlled. This control takes three forms:—

(1) Heating of rooms in cold weather.
(2) Air conditioning, or control of humidity as well as temperature, generally by cooling and drying the air.
(3) Artificial lighting in dull weather and at night.

Out of doors protection is given by suitable *clothing*. The purpose of clothing varies according to the weather; apart from adornment and carrying capacity (with which we are not concerned), we have to consider:—

(1) Protection against cold.
(2) Protection against rain.
(3) Protection against insolation.

### HEATING

The temperature which is regarded as most comfortable for sedentary work is 60–65° F. in Britain and 65–70° F. in North America. This standard temperature varies somewhat according to the nature of the activity carried on; in the U.S.A., for example, it varies from 61° F. for occupations which involve a good deal of bustle to 69° F. in residential apartments, but for practical purposes the figures quoted above may be taken as good averages.

The outside air has a diurnal range of temperature, the mid-day hours being from 10–20° F. or more warmer than the early

morning hours, but the structure and contents of most buildings have a considerable power of storing heat, and the day temperature of unheated buildings changes much less from day to night than that of the outside air. The range depends on the size of the building, the thickness of the walls, and the volume of contents. Large unpolished metal objects such as machinery, and tanks of water, absorb a good deal of heat during the day and give it out again by night, and so tend to stabilise the temperature. R. Grierson (1941) points out that the nature of the walls is important; rooms with panelled walls warm up and cool down much more rapidly than rooms with walls of stone or brick. Further, human beings, cooking apparatus, lights, etc., produce a good deal of heat additional to that supplied by the heating installation. Experience has shown that the amount of power required for heating in any building is proportional to the difference between the average daily temperature of the outside air and 60° F. in Britain or 65° F. in North America. In America it has been found that the actual consumption of fuel in central-heating installations is almost exactly proportional to the difference between 65° F. and the average outdoor temperature. For some purposes the standard temperature may be different; in greenhouses a winter temperature of 45° F. may suffice, while various manufacturing processes may require temperatures up to 75° F.

"*Degree-days*," "*degree-hours*."—The basis of calculation used by engineers is the "degree-day." In countries using Fahrenheit degrees one degree-day is defined as a day on which the mean temperature is 1° F. below the standard. Thus if the standard is 60° F. and in one January the mean temperature is 40° F. and no day has a mean above 60° F., the number of (60) degree-days in the month is $(60-40)\times 31$ or 620. Using the American standard the number of degree-days would be $(65-40)\times 31$ or 775. In a month in which some days had a mean temperature above the standard (*i.e.* degree-days=0) the value could be worked out from the mean temperatures of the individual days. This would be laborious even if the daily values were available, which is not always the case, and for such months J. R. Weeks (1942) gives the rule: For months in which not all days contain degree-days, subtract the average *minimum* temperature for the month from the standard (65° F.), multiply by the number of days in the month and divide by

three. This rule is empirical, based on data for Maryland, and it is doubtful how far it is applicable in other parts of the world.

In countries using Centigrade degrees a degree-day is defined as a day with a temperature 1° C. below the standard. In Germany the latter was taken as 19° C.=66·2° F.; F. Bradtke (H. Reitschels, 1934) gives annual numbers of degree-days calculated on this basis for a number of places in Germany. To correct to ° F. they must be multiplied by 1·8. However, in Germany it was customary not to begin the central heating season until the mean outside temperature fell to 12° C. (54° F.), and to shut it off when the average outside temperature rose again to this figure.

The convention that the fuel consumption depends only on the daily mean temperature and not on the daily range is probably sufficiently accurate for large buildings, particularly for those occupied only during the day, but it is not likely to be true for small buildings such as dwelling-houses, outhouses, etc. For these a correct figure could be obtained only by studying a long series of hourly values of temperature. Apart from the difficulty that such data are available for only a very few places, the labour of the computations would be great. R. Grierson (1941) made the necessary calculations for a sample of days spread over five years at Kew Observatory, Richmond, Surrey, for each month for a series of standard temperatures rising by steps of 5° F. from 35°–70°, and he remarks that it would be impossible to deduce these figures for at least the lower standards from the monthly mean temperatures alone. Figures for other parts of the British Isles are to be taken from a map of "correction factors" to the Kew values. He also gives a series of correction factors for intermittently heated buildings, based on the number of hours which they are occupied each week.

For the growth of plants the critical temperature is taken to be 42° F., and the Meteorological Office, London, compiles figures of the number of days during which the temperature is above and below this limit. These are termed "accumulated temperatures," but are equivalent to "degree-hours" divided by twenty-four. They are obtained by the following expressions:

Maximum temperature below 42° F.: 42 minus mean temperature.
Mean temperature below 42° F. but maximum above 42° F.: $\frac{1}{4}$(42−minimum).
Mean temperature above 42° F. but minimum below 42° F.: $\frac{1}{2}$(Maximum−42)−$\frac{1}{4}$(42−minimum).
Minimum temperature above 42° F.: no accumulated temperature below 42° F.

Accumulated temperatures above 42° F. are calculated in a similar way. Values for different maximum and minimum temperatures are given in Form 3300, issued by the Meteorological Office, London.

These expressions can be applied to find day-degrees below or above other standard temperatures, but the constants probably vary slightly. For a standard temperature of 60° F. a better expression is:—

Mean temperature below 60° F. but maximum above 60° F.: (60—minimum)/5.
Mean temperature above 60° F. but minimum below 60° F.: 2(Maximum—60)/5—(60—mimimum)/5.

These expressions can only be evaluated from daily values of maximum and minimum temperatures. It is desirable to find some simple expression from which the approximate number of degree-hours can be calculated from the climatic data readily available for most meteorological stations.

If we have observations of shade temperature taken every hour over a period of years we can form a *frequency distribution*, which rises to a hump near the mean temperature and spreads out on either side. An example is shown in Fig. 29, in which the vertical scale represents the percentage frequency of occurrence of temperatures within 0·5° F. on either side of the temperature in ° F. given by the horizontal scale. It refers to hourly readings of temperature in April at Kew Observatory. The ratio which the width of such a diagram bears to its height, if the horizontal and vertical scales are unchanged, depends on the variability of the temperature. A similar diagram for New York, for example, also for April, would be about one-third broader and only three-quarters of the height, because April temperature is more variable in New York than in London.

For our purposes, however, a more convenient way to show the figures is by means of a curve known as an "ogive" or cumulative curve, which shows the total frequency below or above any temperature from the lowest to the highest (Fig. 30). From such a curve the number of "degree-hours" below any temperature can be obtained very simply by drawing a perpendicular from the base line at the required temperature up to the curve, and measuring the area between this vertical and the curve (vertically shaded area in Fig. 30 with standard temperature of 60°). The area can be measured with a plani-

meter or simply by counting the number of squares. If the curve is drawn on a vertical scale of 1 inch to 5° F. and a horizontal scale of 1 inch to 10 per cent., an area of one square inch is equal to 50 degree-hours per 100 hours or 360 degree-hours

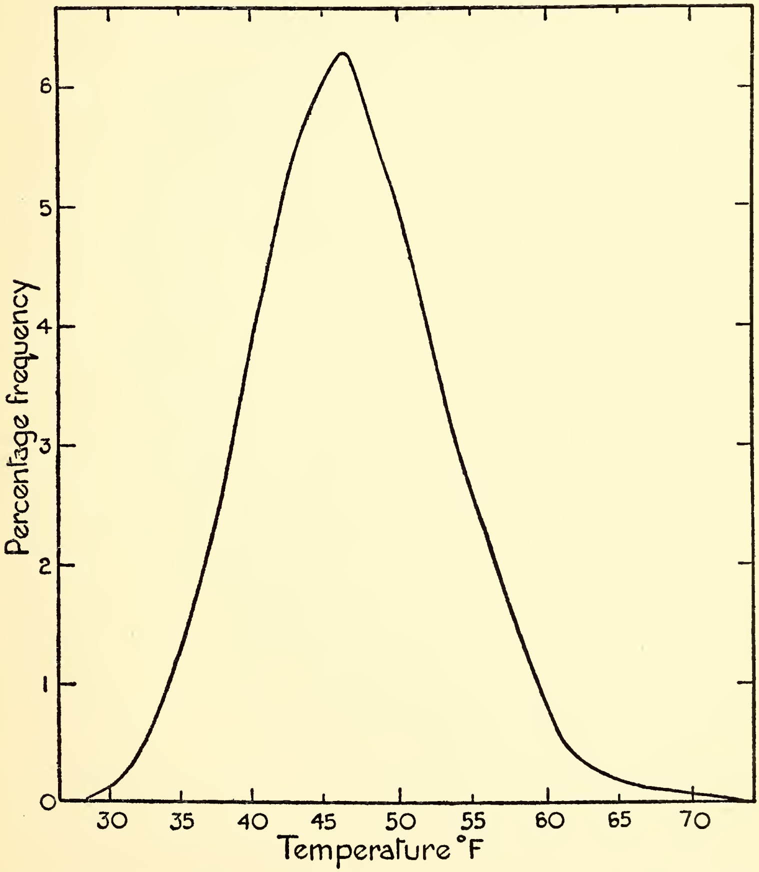


Fig. 29.—Frequency distribution, hourly temperatures, Kew Observatory, April.

per month of thirty days. The number of degree-hours above the standard temperature is given by the area above the curve to the right of the vertical line through that temperature (horizontally shaded area in Fig. 30).

Hourly readings of temperature are not available for many places, and even if they are the computation of frequencies is

laborious. An approximate cumulative curve can be constructed without much difficulty if we have the following data, which are generally available for each month:—

Mean temperature.
Mean daily maximum and minimum temperatures.
Mean monthly maximum and minimum temperatures.
Highest and lowest recorded temperatures.

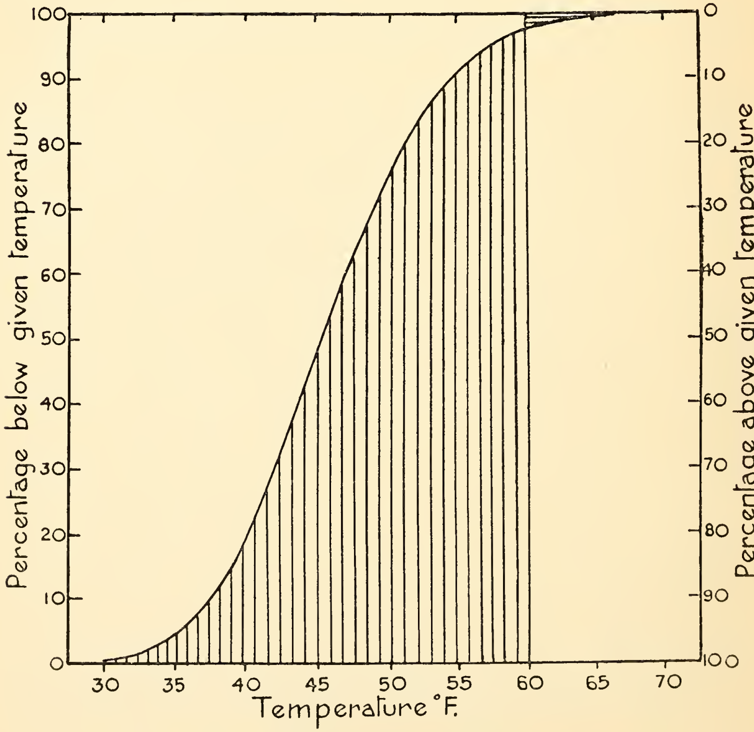


Fig. 30.—Ogive or cumulative curve of temperature.

The mean temperature should be an approximation to the mean of the twenty-four hours. This is given for many places, but the British and American practice is to take as the mean temperature the mean of the mean daily maximum and mean daily minimum. This is, on the average, about 1° F. too high, and 1° F. should be subtracted from the published mean if it is obtained in this way.

In temperate regions we can, without great error, assume that

half of the hourly temperatures lie below the mean temperature and half above. Hence we mark a cross on our diagram where the vertical representing the mean temperature intersects the horizontal representing 50 per cent. (Fig. 31).

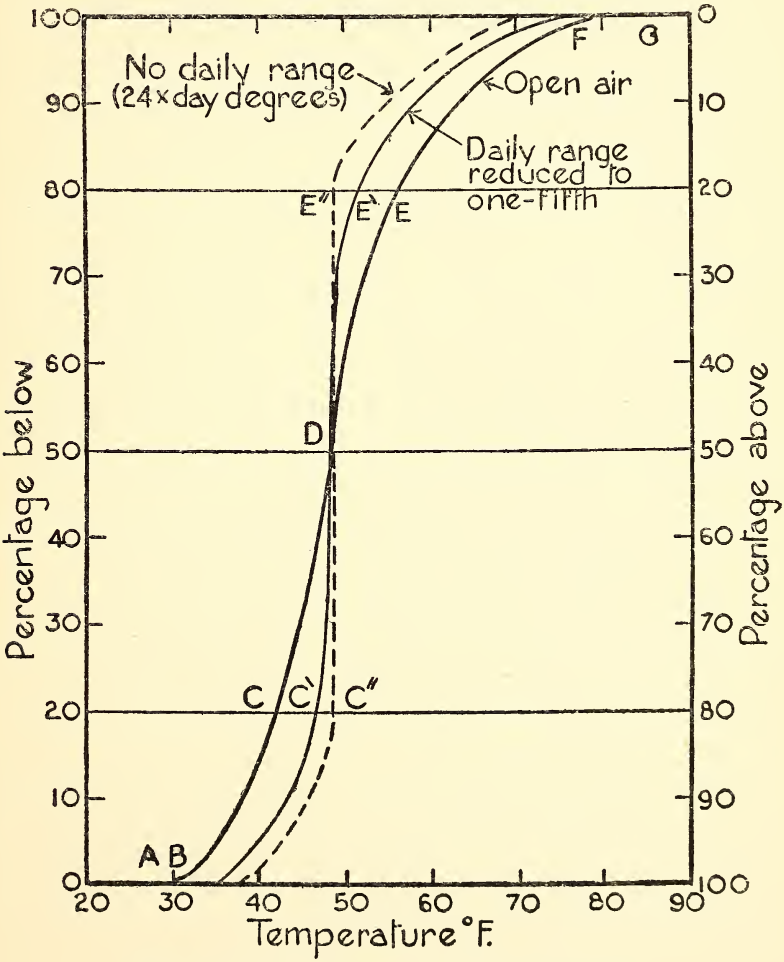


Fig. 31.—Construction of cumulative curve.

Roughly one-fifth of the hourly observations lie below the mean *daily* minimum, and one-fifth above the mean *daily* maximum. Hence we mark these figures on the horizontals representing the 20 per cent. and 80 per cent. lines. About one

in 200 of the hourly observations lie below the mean *monthly* minimum, and one in 200 above the mean *monthly* maximum. These values are accordingly marked on the horizontals for 0·5 and 99·5 per cent.

Finally, the lowest and highest recorded temperatures mark the extreme ends of the curve. Having plotted these points we draw a smooth curve through them and measure off from it the number of hour-degrees below or above any standard temperature required. For New York, April, we have (1930–39):—

| | |
|---|---|
| Lowest recorded . . . . . | 27° F. |
| Mean monthly minimum . . . . | 31 |
| Mean daily minimum . . . . | 42 |
| Mean temperature . . . . . | 49 |
| Mean daily maximum . . . . | 57 |
| Mean monthly maximum . . . . | 79 |
| Highest recorded . . . . . | 88 |

In Fig. 32 the estimated curve constructed from these figures is shown by the thick line and the observed curve by the thin line. The agreement is excellent.

All buildings smooth out the variations of external air temperature to some extent; on the other hand, no building (except perhaps underground cellars) is so perfectly insulated as to have, if unheated, no diurnal variation of temperature. The daily range of temperature inside an unheated building is a fraction of that in the outside air, the magnitude depending on the size of the building, nature of its contents, thickness of walls, amount of ventilation, etc.

Inside a house of moderate size the daily range appears to be from one-third to one-fifth of that in the outside air. Not many figures are known to me, but A. J. ter Linden (1938) gives some thermograph curves for houses in the Hague. I analysed one pair of these, comparing a room on the ground floor with the outside air, with the following results:—

| | Outside air | Inside room |
|---|---|---|
| Mean max. ° F. | 71·8 3 p.m. | 68·0 7 p.m. |
| Mean min. ° F. | 61·5 4 a.m. | 65·8 8 a.m. |
| Range ° F. . | 10·3 | 2·2 |

Both maximum and minimum inside the building lag about four hours behind those in the outside air. In a large factory in summer the daily range is about one-fifth or less of that in

the air outside. Hence we can make an approximate correction of the curve in Fig. 31 to conditions inside a large building by shifting our 20 per cent. and 80 per cent. points C and E to new

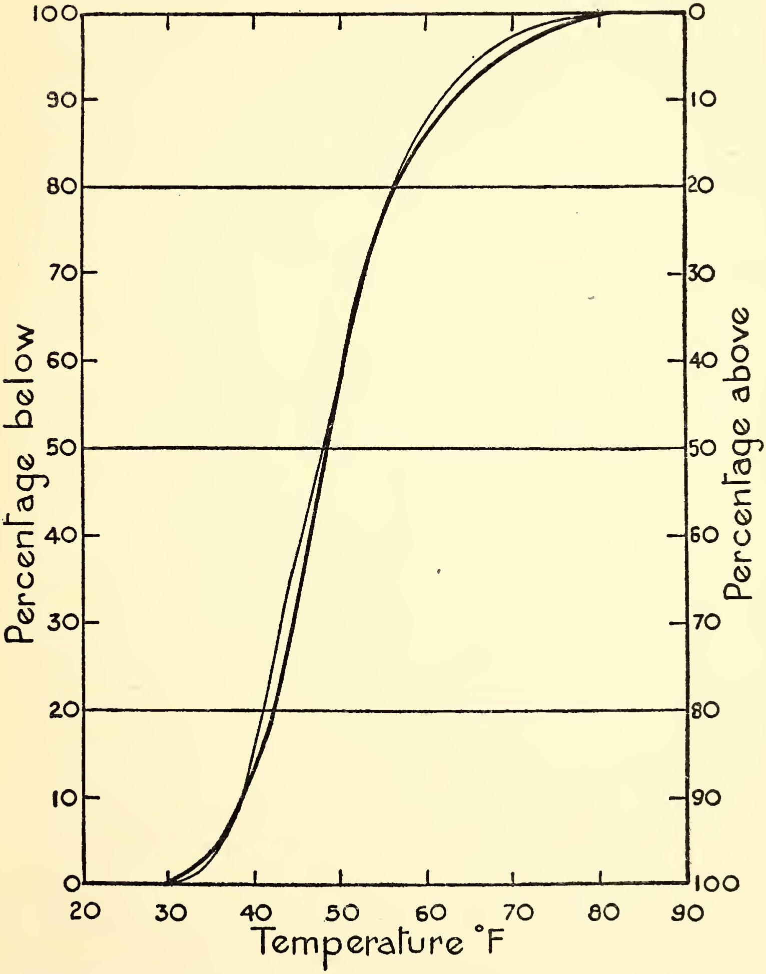


Fig. 32.—New York, cumulative hourly temperatures, computed and observed.

positions C′ and E′ nearer to the vertical through the mean temperature by an amount equal to four-tenths of the daily range. The whole of the curve from A to C is shifted to the right by the same amount and the whole curve from E to G is similarly shifted to the left. Between C and E a smooth curve

is drawn passing through D. Over most of its length this part of the curve will be coincident with the vertical through the mean temperature. The construction is shown in Fig. 31.

The use of day-degrees implies that the daily range inside the building is zero. Hence to convert the curve of Fig. 31 to approximate day-degrees we mark the points C″, D and E″ all on the vertical through the mean temperature (broken line in Fig. 31). In practice the curve should be rounded off so that the central part is not quite vertical. The true curve certainly lies between CE and C″E″.

*Maximum Load to be expected.*—In addition to the number of day-degrees or hour-degrees of temperature below the standard, we require to know the lowest effective temperature to be expected in order to assess the heating power which the installation must be able to put out. The best figure to adopt for this purpose is the mean annual minimum temperature, as given in Appendix I. A map showing the distribution of this temperature over the world is given by C. E. P. Brooks and G. L. Thorman (1928). The temperature of the outside air falls below this for a short time every other year, but mostly at night, and the heat content of the building itself should be capable of carrying over these rare extremes. The heaviest demand on a heating system comes when a building which is only intermittently occupied, such as a hall, has to be warmed up for occupation during a period of exceptional cold. Since the building begins to lose heat as soon as its temperature rises above that of the air, the heating period should be as short as practicable, consistent with reasonable initial cost. For this reason the heating plant should be capable of slightly more than maintaining the required indoor temperature when the external air temperature is at the mean annual minimum.

*Other factors in heating and cooling.*—The number of degree-days or degree-hours by which the temperature of the outside air falls below the required temperature is only one of the factors affecting the amount of heat required to warm a building. We have to consider also:—

Other sources of heat, especially solar radiation.
Heat losses by conduction through walls, floor, windows and roof.
Heat loss by warmed air escaping from the building.

The warming of buildings by solar radiation was discussed in Chapter II (p. 57). The heat transmitted through windows is much greater than that through walls, and for that reason it is desirable to have as much window space as possible on the south side. Some types of glass transmit more radiation than others, and this point may be worth considering in cold, sunny climates. The possibility of conserving solar heat by day for release at night is being tested in the U.S.A. (M. Telkes, 1947). The conserving agent may be a large cellar water tank or a suitable chemical.

Heat loss by conduction was also discussed in Chapter II (p. 75). The loss, like the gain, is greatest through windows, and as the loss increases with the wind speed (roughly according to the square root) it may be desirable, as far as is compatible with adequate daylight, to limit the area of windows on the side exposed to the most frequent and coldest winds, which in Britain is generally the north-west side. It should also be remembered that on hill-slopes there is a flow of cold air down the slope on clear, calm nights. If a building stands directly in the path of such a flow it will be engulfed in cold air at night, but the airflow can often be held up or diverted by suitable wind-breaks (see p. 266). As most daylight enters through the upper parts of windows, heat can be conserved with minimum loss of daylight by keeping the windows high up in the walls on the side exposed to the coldest winds.

The heat carried away by the warmed air leaving the building is an important source of loss, which obviously can be minimised by cutting down the flow of air through the building. Most buildings in Britain are probably over-ventilated in the sense that an unnecessary amount of air passes through them without always circulating properly, so that the fresh air fails to reach some parts while other parts suffer from draughts. In the cold regions of the United States the modern practice is to cut down the flow of air through the building, but to maintain a good circulation within the building by fans and by suitable connecting channels. Walls, floors and ceilings are warmed and well insulated. Central heating is general; open fires are hardly known except as "decorations," and C. C. Handisyde (1947) suggests that this is because the abundant winter sunshine provides the necessary source of high-temperature radiation.

By far the greater part of the heating in Britain is done either directly or indirectly by the burning of coal, and much of this, especially in private houses and offices with open fires, is burnt in a very wasteful way. With the manifold increase in the price of coal in recent years this waste is no longer tolerable, and the general adoption of more economical methods of coal consumption is urgent. R. Fitzmaurice (1942) points out that the consumption of coal for heating per head in Britain was much greater than in Germany, where winters are colder, and yet a better standard of heating was maintained in German than in British buildings. The open grate has been discarded in almost every country of the world, except Britain, in favour of the closed stove.

In countries with very cold winters the practice of heating a whole district from a single boiler is being developed, but Fitzmaurice doubts its practicability in Britain because of the great variability of our winter climate. The whole subject of heating small buildings is at present in a stage of transition and new developments are likely to emerge from the researches now being carried on.

## THE CONTROL OF TEMPERATURE AND HUMIDITY; AIR CONDITIONING

The temperature of the air is not the only condition which affects the feeling of well-being and energy; relative humidity and wind movement are also important. For this reason the concept of "effective temperature" has been introduced; this is defined as the temperature of motionless, saturated air which would induce the same feeling of heat or cold in a sedentary worker wearing ordinary indoor clothing as that given by the actual conditions of temperature, humidity and air movement. A number of charts of effective temperature at various air temperatures, relative humidities and air speeds have been published; a convenient one is that of the American Society of Heating and Ventilating Engineers (New York, 1944). In the U.S.A. the optimum effective temperature is regarded as about 67° F., but may range from 65° F. in winter to 73° F. in summer. In Britain the optimum effective temperature is considerably lower, probably about 60° F.

The air temperature, wet-bulb temperatures and relative

humidities which give effective temperatures (E.T.) of 60° and 67° F. with air movement of 20 ft./min. are as follows:—

| Effective temperature ° F. | 60 | | | | | 67 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Air Temperature, ° F. | 60 | 61 | 62 | 63 | 64 | 67 | 68 | 70 | 72 | 74 |
| Wet-bulb, ° F. | 60 | 57 | 54 | 51 | 48 | 67 | 65 | 61 | 57 | 54 |
| Relative Humidity, % | 100 | 76 | 55 | 37 | 19 | 100 | 86 | 59 | 35 | 17 |

Increased air movement lowers the effective temperature, even when the air is saturated. An air movement of 20 ft./min. is practically still air; an air movement of 100 ft./min. is appreciable, and this reduces an E.T. of 60° to 57° or 58° F., and one of 67° to 65° or 66° F. For this reason, switching on an electric fan brings a feeling of coolness, and in moderately unfavourable conditions is a substitute for air-conditioning.

Even at optimum E.T. very moist or very dry air is unpleasant; the relative humidity should not be above 70 per cent. or below 30 per cent. The optimum temperature and humidity vary somewhat in different countries, depending to some extent on what people are used to. S. F. Markham (1942) finds that the ideal temperature in which men work hardest and most efficiently lies between 60° and 76° F., and the ideal humidity between 40 and 70 per cent. Hence, in extreme climates the mere warming or cooling of the air is not sufficient; the humidity also needs to be adjusted, but not necessarily to a fixed figure.

Fig. 33 shows in diagram form the comfort and danger zones in terms of air and wet-bulb temperatures. The operative part of the diagram is included between the two exterior sloping lines representing relative humidities of 100 and 0 per cent.; conditions outside these limits are physically impossible. The inner sloping lines show relative humidities of 70 and 30 per cent. and mark the limits of comfortable humidity. The two broken lines near the top of the diagram show the limiting conditions for heat-stroke calculated by D. Brunt (1947). Above the upper broken line heat-stroke is probable in a nude subject, resting in an air current of 17 ft./min., and above the lower broken line heat-stroke is likely to be brought on by moderate physical activity. For more active air movement (about 200 ft./min.) the limit above which heat-stroke is probable is: in saturated air, dry- and wet-bulb about 95° F.; relative humidity 34 per cent., dry-bulb 122° F., wet-bulb 94° F. The curved

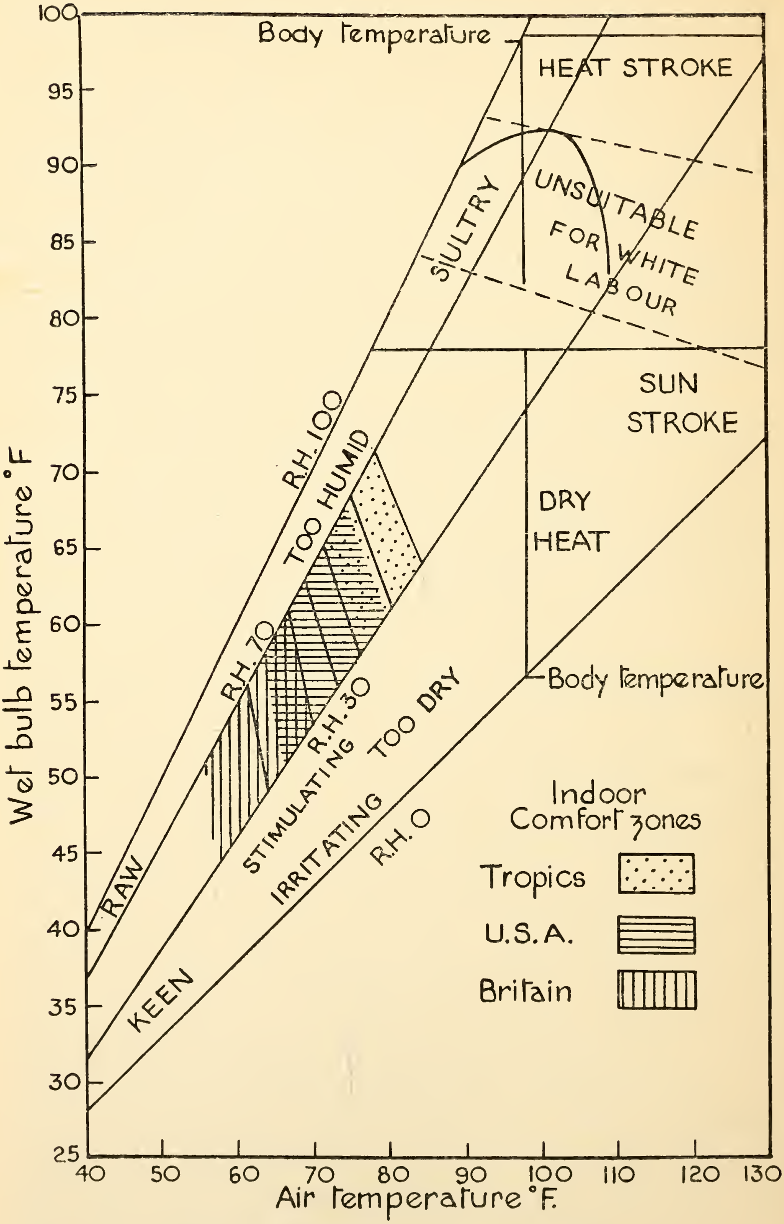


Fig. 33. Comfort and danger zones.

line near the top of the diagram limits the temperatures above which heat-stroke is probable, according to R. G. Stone (1941). The horizontal line at wet-bulb 78° F. shows the limit for sustained white labour.

The stippled area marks the comfort zone for acclimatised residents in hot tropical regions, and the shaded areas the accepted comfort zones in the U.S.A. and Britain. The middle lines in these shaded areas represent effective temperatures of 73°, 67° and 60° F. respectively.

The process of maintaining a suitable temperature and humidity is known as "air conditioning." This also includes the cleansing or purifying of the air and sometimes introducing a suitable rate of air movement. In cold weather air conditioning implies warming and generally adding moisture to the air; in hot weather it means cooling and removing moisture.

*Air conditioning in cold weather.*—In very cold weather the air, even if saturated, contains only a small amount of moisture, and when it is warmed up to a comfortable temperature it becomes uncomfortably dry. In such conditions, for maximum comfort water vapour must be added to the air. For example, if the outside air is at 20° F. and 80 per cent. relative humidity it contains only 1·06 grains of water per cubic foot, and when warmed to 65° F. it will have a relative humidity of only 12 per cent. The comfortable limits of relative humidity are between 30 and 70 per cent.; if we adopt 50 per cent. as a standard, it is necessary to add about 2½ grains of water to every cubic foot or 5·7 grams to every cubic metre of air brought into the building, after it has been raised to the requisite temperature. In meteorological tables weight of water vapour is generally given in grams per cubic metre; this can be converted to grains per cubic foot by multiplying by 0·44.

The calculation given above was based on the assumption that the building into which the warmed air is introduced does not itself contain any source of water vapour. That assumption is not usually correct. The occupants of a room themselves add water vapour to the air, mainly by breathing, and in addition many of the objects in a room can absorb moisture at high relative humidities and release it when the humidity falls. In practice it can be assumed that the relative humidity of the air in an occupied room in winter will be raised by 5 to 10 per cent. from these causes—the figure naturally varies according to the

number of cubic feet of space per person and the rate of ventilation. In rooms which are rather densely populated the occupants themselves are likely to maintain the relative humidity within the comfort zone. In less crowded rooms the occupants sometimes maintain the humidity by the crude but effective method of placing a saucer of water in front of or on the radiator. Air conditioning as distinguished from simple heating is therefore relatively unimportant in cold weather.

*Air conditioning in hot weather.*—Although the cooling of air is a comparatively recent development—it is much more difficult to cool air than to heat it—there already exists a large literature about its beneficial effects. H. C. Bazett (1948) remarks that in naval vessels in the tropics, blacked out and closed down for action, the air became 10° F. or more hotter and also more humid than the outside air, and in submarines conditions were even worse, and led to a serious loss of efficiency. T. Bedford (1946) points out that the effect is increased by the crowding of modern warships with machinery, decreasing the available air space and requiring a larger crew to work them. After air conditioning was introduced into submarines the crews became the healthiest of the whole fleet. In very hot countries entering an air-conditioned room at a temperature much below that of the outside air is liable to give a chill. A sudden change in the effective temperature by 3° F. is tolerable, however, and in tropical factories the effect of cooling the air to 80° F. and slightly dehumidifying was found to be very beneficial. The effect of air conditioning in a Chinese cotton factory was referred to on p. 32. Outdoor workers gain in efficiency by sleeping in air-conditioned bedrooms, but this is only practicable in large solid buildings such as blocks of flats; the light open construction usual in many tropical buildings is not suitable for air conditioning. The tolerance of hot humid conditions varies widely even between men of the same race, and should be tested before a man undertakes regular work in such conditions.

In Britain it is not often necessary to cool and dry the air even in summer—the chief need in large towns is to cleanse it. High temperatures are occasionally experienced, but the relative humidity on such occasions is nearly always below 60 per cent., and more often than not below 45 per cent. F. H. Dight (1934) found that at Kew, London, in the thirty-four years 1900–33 the hourly temperature exceeded 85° F. at least

once in nineteen of the years, the total duration being 232 hours spread over sixty-one days. The average relative humidity was 41 per cent. The highest wet-bulb temperatures were 75·7° F. on 29th August 1930 (maximum air temperature 89·1° F., relative humidity 52 per cent.) and 75·5° F. on 20th July 1900 (air temperature 89·4° F. relative humidity 51 per cent.). These two days also had the highest water contents in the air, 17·1 and 16·9 gm./cu.m. respectively, and they may be taken as representing about the worst combination of high temperature and humidity likely to be met with in London. The highest air temperature of 93·9° F. on 9th August 1911 was accompanied by a wet-bulb maximum of only 71·4°, the relative humidity being 30 per cent. Dight remarks that the most sultry conditions in Britain often come at the end of a warm spell when the air temperature is falling while the relative humidity is rising, so that the wet-bulb temperature changes little. These conditions usually end in a thunderstorm. S. F. Markham in a fascinating book (1942) points out that civilisation developed first in those parts of the world which enjoyed an *average* climate nearest to the ideal, *i.e.* the sub-tropics. But in these regions there are many hours of the day, and even whole seasons, when the weather is too hot or too humid for full efficiency. Consequently as methods of heating improved and the winter temperature became less important, the centres of civilisation moved to higher latitudes, where the summers are less enervating. He attributes the rise of Greece to the discovery of the hypocaust system of heating, and of Rome to glazing and public baths. The fall of Rome was preceded and accompanied by the neglect of the housing system, and leadership passed back to Islam and the 70° F. isotherm. The successive discoveries of the chimney, coal, gas and electricity have made heating more and more easy and exact, and now the ideal climate is one which is just right in summer and can easily be controlled indoors in other seasons by heating—in fact the climate of England.

The development of economical air conditioning, however, may reverse the process, and make the optimum climate for industrial purposes that which lies near the optimum for the greatest part of the year; Markham suggests a mean annual temperature of 60° F. as possibly marking the greatest advances of civilisation in the future.

## LIGHTING

Artificial lighting has reached such a high level that there is a tendency to regard daylight lighting as unimportant. R. Fitzmaurice (1942) points out that while the requirements of different occupations in artificial lighting have been codified, and there is a strong body of professional skill to meet those requirements, few people bother about day-lighting, and he calls attention to a range of "daylight factor protractors" due to A. F. Dufton of the Building Research Section, for the rapid calculation of the daylight efficiency of any system of windows. The illumination at different distances from windows of various sizes and shapes with different skylines has been calculated in detail by T. Smith and Miss E. D. Brown (1944). They point out that the area of sufficient illumination at table height (2 feet 9 inches) from a window is an ellipse with its longest axis parallel to the window. For living rooms the window area should be sufficient to give one per cent. of the outside illumination, but work requiring a good light should have at least 2 per cent. They also emphasise the importance of *high* windows for three reasons. First, the area illumined increases with the window height; an unobstructed window 6 feet wide rising 5 feet above table level gives an effective area for close work of 89 square feet, while one $2\frac{1}{2}$ feet high gives only 44 square feet. Secondly, obstructions such as buildings cut down the effective illumination much more with low than with high windows. Finally, daylight entering at a low angle (less than 25°) is more fatiguing than that entering at a high angle.

The illumination is very much greater when the sun is shining than when it is obscured. The worst condition is a dense town fog, which often involves day-long lighting, but heavy cloud is almost as bad. Table 10 (p. 68) gives the average daily duration of sunshine in open situations for a selection of places. The duration is cut down by obstacles which raise the sky-line, especially between east and south-east, which obstruct the morning sun, and between south-west and west, which have a similar effect in the evening.

Electric lighting is cheap, even nowadays, but daylight is free and is available for most of the working day. However, there are periods of dusk and night, and other periods of fog or heavy cloud, when artificial lighting is necessary, and the

aim of the architect should be to make the transition from one to the other as smooth as possible, in the home, office and factory. It has been found by experience that artificial light is switched on, on the average, when daylight has fallen to 12 foot-candles, but is not switched off again until it has risen to 100 foot-candles. This difference is probably due partly to the difference in colour, for the eye, adapted to the light of one set of wave-lengths, cannot instantaneously adapt itself to light of different wave-lengths. The transition could be made easier by the use of a system, such as fluorescent lighting, which simulates daylight. Fluorescent lighting also uses less current for the same candle-power.

## VARIATIONS OF THE LOAD ON ELECTRIC SYSTEMS CAUSED BY WEATHER

The following notes are based mainly on a discussion at a joint meeting of the Institution of Electrical Engineers and the Royal Meteorological Society (London. Royal Meteorological Society. 1945).

The use of electricity for heating depends mainly on temperature, but is influenced also by wind speed, relative humidity, insolation and probably also by rainfall and intensity of daylight, since a dull, wet day may give the impression of being colder than a fine bright day, though the actual temperature is the same. The lighting load depends on the duration of daylight intensity below about 60 foot-candles. The loads for both heating and lighting vary regularly from winter to summer, and at different times of day, and this variation can be foreseen and provided for; but in addition there are rapid variations of load due to more or less sudden cold spells, the onset of strong winds and rain, fog and dense cloud.

In the discussion E. B. Powell stated that the largest single factor was temperature, the load increasing slowly as air temperature fell from 80° to 60° F. and then more rapidly, but almost uniformly from 60° downwards. With a temperature of 27° F. the heating load is estimated as three and a half times that at 57° F. Curves shown by C. T. Melling were similar, and indicated that the increase of load per 5° fall of temperature was greater at temperatures below 35° F. than above that figure.

The load due to lighting is small and almost constant so

long as daylight illumination remains above 60 foot-candles. Between 60 and 20 foot-candles it increases fairly rapidly (presumably because of the tendency of people to leave lights on after they are no longer necessary); from 20–0·5 foot-candles the load is almost exactly proportional to the logarithm of the difference between 100 and the actual daylight illumination. The load at 0·5 foot-candles is more than four times that at 20. A daylight illumination of 0·5 foot-candles in the open is practically equivalent to darkness in a room, and at that level lighting is almost that of full night.

Owing mainly to atmospheric pollution, dull, foggy days in London may have an illumination of only 14 foot-candles, so that lighting is necessary all day. The worst conditions occur during overhead fogs. In foggy weather there is almost always an "inversion" of temperature, the air near the ground being colder than that at a height of some hundreds of feet. This prevents the surface air from rising, and the smoke and fog particles tend to accumulate in the surface layer of air. But owing to the heat generated in London in winter the air in the streets and among the buildings is warmed up by two or three degrees (see p. 43), and this is enough to dissipate the fog at ground level. The smoke and fog particles all accumulate between this warmed layer and the level of the inversion, forming a dense pall through which hardly any daylight can penetrate, and full artificial lighting is required all day.

In summer the greatest darkness is brought about by dense thunderclouds, which often come up suddenly and may be extensive. These may reduce the daylight intensity to as low as 4 foot-candles, which is considerably less than that shortly after sunset on an average day. This sudden load imposes a worse strain on generators than do falls of temperature, which generally come on more gradually. Moreover, forecasts of changes of temperature are issued by the Meteorological Office, but forecasts of daylight illumination are much more difficult and, apart from warnings of fog, have not, so far as I know, been attempted.

The temperature and daylight factors can be combined into a formula of the form

$$L=a-b \log I-cT$$

where $L$ is the load on the installation, $I$ is the daylight illumina-

tion in foot-candles, $T$ is the outdoor temperature (° F.), $a$, $b$ and $c$ are constants, which can be determined from the records of any installation by statistical analysis. This relationship has been studied in detail by P. Schiller (1944).

## CLOTHING

Clothing serves three utilitarian purposes, to keep the body warm in cold weather, to ward off rainfall, and to ward off excessive insolation. We can leave out of account here two other purposes, namely to serve as a receptacle for impedimenta and to adorn the body, as these are not connected with climate.

Indoors excessive insolation and rainfall do not occur and the building ought to be kept at a comfortable temperature so that protection from cold should not arise. In occupations requiring considerable physical effort or which have to be carried on in a high temperature the problem is to keep the body cool and dry by getting rid of perspiration, and light loose-fitting garments are called for. In the open, however, protection from cold, rain and excessive insolation are all important. For a detailed catalogue of complete outfits of clothing, including footwear, to suit different types of extreme climate see D. H. K. Lee and H. Lemons (1949).

*Protection from cold.*—The insulating power of a thickness of cloth is almost proportional to the thickness of the layer of "dead air" between the surface of the outer layer of cloth and the body. This includes not only the air spaces within the different layers of cloth, but also those between them. Closely fitting garments reduce the latter and are therefore unsuitable in cold climates.

Wind lessens the insulating power of clothing in two ways—it penetrates the cloth and disturbs the layer of "dead air," and by pressing the clothes against the body it destroys the insulating layers between the different layers of cloth and between the latter and the body. The first loss of insulation can be lessened by wearing an outer covering of as low a permeability as is consistent with getting rid of perspiration. Completely wind-proof garments are not desirable because with no ventilation at all the inner garments become soaked and lose about half their insulating power.

P. Larose (1947) examined a number of specimens of cloth

and found that permeability ranged from 0 to 193 cubic feet per square foot per minute under a pressure difference of ½ inch of water across the fabric. Since the weight of a layer of water ½ inch deep and 1 square foot in area is 2·6 lbs., I take this as equivalent to a wind speed of about 30 m.p.h. directed normally against the cloth. He gives curves showing the thermal insulation in "clos" of cloths of different permeabilities from 8 cubic feet per square foot per minute upwards, at different wind speeds. One "clo" is the thermal resistance of clothing necessary to maintain in comfort a sitting-resting subject in a normally ventilated room (air movement 20 feet per minute) at a temperature of 70° F. and a relative humidity of less than 50 per cent. It is equivalent to a temperature difference across the cloth of 0·18° C. per gm. calorie per hour per square metre, or 0·88° F. per B.T.U. per hour per square foot.

In calm air the insulating power of all fabrics is about equal at 1·75 clo, and except for the most porous material this holds up to a wind speed of 6 m.p.h. When the speed rises above 6 m.p.h. the curves begin to diverge, and are farthest apart with a wind of 20 m.p.h. At this speed the insulation of the least permeable fabrics (permeabilities 8 and 13 cubic feet) had decreased to about 1·2 clo, that of the most permeable (36 and 193 cubic feet) to 0·8 and 0·6 clo respectively. Above 20 m.p.h. the insulation of the less permeable materials continues to decrease steadily, but that of the more permeable changes little. At 60 m.p.h. the curves would meet, so that in a very strong wind the nature of the material makes little difference. As, however, outdoor work would be difficult in winds much above 20 m.p.h., and impossible in winds of 60 m.p.h., the latter conclusion is of academic interest only. The author's conclusion is that for work in light and moderate winds it is of advantage to wear a light covering fabric which is nearly, but not quite, impervious to wind.

The greatest need for protection against cold is in the Arctic countries in winter. Research into the best forms of protective clothing in Arctic Canada is described on p. 167.

*Protection against rain.*—Coverings to protect the wearer against rain are of two types, waterproofs with a layer of rubber (mackintoshes) or oiled fabric (oilskins) which are completely impermeable to air and water vapour as well as to liquid water; and water-repellant substances which permit air and water

vapour to pass. The first type is proof against continuous heavy rain (unless the impermeable layer is cracked or worn into holes), but is equally proof against the escape of perspiration from within. The second type, which includes many "raincoats," is showerproof, but not proof against continuous heavy rain; its advantage is that it permits perspiration to escape.

Natural wool because of its greasiness and hairiness is a fairly good water-repellant and there are a number of patent materials which are better, but this book is hardly the place to discuss them. A "raincoat" in this sense is cloth coated with a hydrophobic substance such as wax, but the air spaces in the cloth are not filled, so that it is permeable to air and water vapour to an extent depending on the size of the pores. It resists wetting by raindrops and rain does not form a film of water, but it permits the passage of water under pressure. For this reason heavy rain can penetrate a raincoat on nearly horizontal surfaces such as shoulders, and driving rain can eventually penetrate vertical surfaces. The best raincoat material can stand up to several hours of rain and even then pass water slowly.

An investigation into the properties of water-repellant substances was carried out by the National Bureau of Standards, Washington (J. W. Rowen and D. Gaglierdi, 1947). The authors found that the most important factor is the angle of contact which the surface of a drop resting on the fabric makes with the surface of the fabric. If this angle exceeds 90°, so that the shape of the drop is larger than a hemisphere, the contact between drop surface and fabric is on the outer side of the latter; the inner surface remains dry and the fabric is a good water-repellant. If the angle of contact is less than 90° the shape of the drop is a flat segment of a sphere, contact between the surface of the drop and the fabric is on the inner surface of the latter, and the water-repellant properties are poor.

A number of tests are available for assessing the efficiency of water-repellant fabrics, some of which measure the resistance to penetration of water under pressure, and others resistance to the impact of drops, but none of these is completely satisfactory. The "drop-penetration" test appears to be the best because it approximates most nearly to the natural conditions.

The value of a water-repellant cloth depends not only on its resistance when new, but also on the extent to which it decreases after wetting and subsequent drying, and also after

cleaning. The resistance of some fabrics was found to be nearly halved after five wettings and dryings.

*Protection against insolation.*—The sun's rays may be divided into actinic (producing chemical changes), light rays, and heat rays. All the sun's rays are actinic to some extent, but the most active are the short "ultra-violet." It is these rays which cause inflammation of the skin (erythema) and sunburn. When the skin becomes pigmented, as in sun-tan after the inflammation has died down, the pigment forms a protection against further inflammation.

At one time the actinic rays were believed to be the cause of many of the troubles such as heat-stroke, sunstroke, conjunctivitis and nervous diseases which affect white settlers in the tropics, but they are now regarded as less dangerous than the light and heat rays. Nevertheless, they probably contribute to the effect of the latter and some precautions against them are desirable. Sir Aldo Castellani (1938) quotes Woodruff as advising that in the tropics the outer clothing should be white, grey or yellow, which reflect a large proportion of the light rays, and underclothing should be black or yellow, which he thinks stop the ultra-violet rays (this is not certain). The danger from actinic rays is greatest in dry, tropical countries such as Egypt; in moist heat the water vapour in the air stops a large proportion of the ultra-violet, and in fact in such conditions many whites do not tan, but their skin assumes a peculiar whitish tinge. This does not seem to have any ill effects.

The intense light of tropical regions is responsible for various eye troubles, especially tropical photophobia with headaches and neuralgia, glare conjunctivitis, night blindness, etc. Protection of the eyes by adequate headgear and by dark glasses or Crookes' non-actinic glass with side-pieces is desirable. In towns much of the glare is due to reflection from white buildings, and this can be minimised by colouring the walls green or brown instead of white.

The infra-red or heat rays in solar radiation are now considered to be the main cause of sunstroke and sun-exhaustion. They are absorbed by the body and especially by the scalp, causing failure of the heat regulation. Castellani advises all Europeans in the tropics to wear broad-brimmed pith helmets or topees covered with white or khaki cloth and lined internally with red, yellow or black. There must be free ventilation and

free circulation of the air inside, as otherwise the head would become very hot. The effectiveness of the helmet is increased if a sheet of aluminium foil is moulded over the top, covered with a white cloth merely for appearance. He described experiments which showed that the temperature under such hats exposed to the sun was several degrees lower than under similar helmets without aluminium foil. White is, of course, by far the best outside colour, air inside ordinary white helmets being some 20° F. cooler than under similar helmets coloured black. For the effect of colour in cloth see p. 178.

# CHAPTER XII

## ALTERING THE WEATHER

IN this chapter we deal briefly with some attempts to change the actual weather in the open. The scale of processes in the atmosphere is so great that hitherto man's purposefully directed efforts have had only small and local results; the *unintentional* effects of human activities such as extensive deforestation on the climate have been much greater, but unfortunately they have usually tended towards a deterioration of climate.

The various attempts may be classified under the following heads:—

(1) Rain-making and fog dispersal.
(2) Prevention of hail.
(3) Protection from lightning.
(4) Frost prevention.
(5) "Wind-breaks."

### "RAIN-MAKING," FOG DISPERSAL

The possibility of inducing rain to fall by artificial means is at present a matter of controversy. It is generally agreed that rain cannot fall unless a cloud is present; the question is whether in certain circumstances an existing cloud can be made to give rain when, if left to itself, it would not.

Cloud particles are formed when the amount of water in the air exceeds that which can be held as water vapour. This happens when moist air is ascending and cooling by expansion. The surplus water vapour condenses on nuclei in the form of water droplets, which are visible as cloud. In absolutely clean air the water vapour would not condense readily, but would remain as vapour in a state of super-saturation. In nature, however, sufficient nuclei of condensation are almost always present. J. R. Ashworth (1929) considered that there was some evidence that rainfall in the manufacturing town of Rochdale was least on Sundays, when the mills are closed, but in the discussion of his paper the evidence was not regarded as strong.

So long as the temperature of the cloud layer is above 32° F.

the cloud will consist entirely of water drops of small and generally uniform size, which have the same electric charge and do not coalesce readily to form raindrops. If the temperature falls below 32° F. the water drops do not immediately freeze unless some ice-particles already exist in the air. Instead they continue to exist as "super-cooled" water, and can maintain this state at times down to a temperature of −10° F. (−23° C.) and even lower, but they cannot retain the liquid form at a temperature of −31° F. (−35° C.), and a super-cooled water drop at any temperature below 32° F. freezes as soon as it touches a particle of ice.

In air which is just saturated and contains only water drops, the latter will be in equilibrium, *i.e.* they will neither grow by condensation nor decrease by evaporation. If some of the water drops are turned to ice by contact with ice-crystals this equilibrium is disturbed. Air which is in equilibrium with water drops is supersaturated for ice, so that water vapour condenses and freezes on the ice-particles. The loss of vapour from the air is made good by evaporation from the remaining water drops. The ice particles grow at the expense of the water drops until they are large enough to fall out of the cloud. If the air below is cold enough for them to remain frozen they fall as snow; if they melt on the way down they turn into rain.

It follows that save in exceptional circumstances a cloud cannot give appreciable rain unless (*a*) it extends into the freezing level in the atmosphere, and (*b*) ice-crystals are present on which raindrops can form. Clouds which do not extend into the freezing level rarely give more than fine rain or drizzle. The exceptions occur chiefly in tropical regions where the freezing level is very high, but the air contains so much moisture that large raindrops can form without the intervention of ice.

The modern theory of rain-making is that the place of the natural ice-crystals can be taken by "seeding" the cloud with small pellets of some substance which is either very cold or very hygroscopic. In practice the substance usually employed is "dry ice" (solid $CO_2$) scattered from an aircraft flying just above the cloud. The pellets of "dry ice" falling through the cloud cool a thin tube of air to below the temperature of −31° F. at which water drops necessarily freeze without the intervention of ice. Each pellet therefore leaves behind it a trail of ice-particles, which are spread by turbulence through neighbouring

parts of the cloud. T. Bergeron (1949) points out that a nice adjustment of conditions is required for an appreciable amount of rain to be produced by this process. In the first place, the cloud must be dense and thick to contain enough water to supply the rain. This can be the case only if there is a considerable depth of cloud at heights below the freezing level. Secondly, the cloud must extend above the freezing level or any ice-particles produced would quickly melt. Thirdly, there should be sufficient updraft of air below and through the cloud to support the growing ice-particles until they reach a good size and also to maintain the supply of moist air necessary for prolonged rain. These three conditions are met with only in large cumulo-nimbus or thunder clouds. But such clouds generally grow sufficiently high to reach the level at which ice crystals exist naturally, which is usually at a temperature of 15–20° F., so that they would produce rain without artificial "seeding." In most experiments in which seeding by solid $CO_2$ has produced rain there is no means of knowing whether or not rain would have fallen in any case. Some meteorologists hold the view that seeding makes no difference. However, in an experiment in Australia (E. B. Kraus and P. Squires, 1947), out of many hundreds of cumulus clouds present, two were seeded and these two were the only ones to produce rain. The question is still open, but at present it seems unlikely that rain-making will have any appreciable economic importance.

In some cases seeding by solid $CO_2$ has the opposite effect of *dissipating* thin stratus cloud, and Bergeron remarks that this may be useful for aviation and at coastal holiday centres. Fog dispersal, *i.e.* the local clearance of fog from airfields, which was much discussed during and shortly after the war, depends on a different principle. By the expenditure of a sufficiently great amount of fuel it is possible to keep the temperature of the air over a small patch of country above the dew-point and hence free of water fog. The cost is so great that its use is only justified in exceptional circumstances. Fog clearance is not likely to have any industrial or commercial applications.

## PREVENTION OF HAIL

Hail is formed when a pellet of ice alternately falls into the level of liquid super-cooled water drops in the cloud and is

carried up again into the region of ice-crystals. In the former it acquires a layer of hard, clear ice; in the latter it grows by the accretion of crystalline ice which contains a good deal of air and is more or less opaque. Large hailstones often consist of several pairs of these concentric layers, which can be seen when the hailstone is cut open, and the structure has been described as resembling that of an onion. Each pair of layers represents an upward and downward journey across the boundary between the level of super-cooled water and that of ice-crystals. Large hailstones require a strong upward current of air to support them (see p. 210) and hail is formed only in violently ascending currents such as those which accompany thunderstorms and tornadoes.

The weapon most usually employed against hail is the "hail cannon," the theory apparently being that the shock wave produced by firing the cannon vertically upwards penetrates the layer of super-cooled drops and shakes them into freezing. In the frozen state they are no longer available to add to the size of hailstones. A less plausible argument is that the shooting may break up the rising current which bears the hailstones aloft. According to Col. Ruby (1938), in the wine-producing regions of southern Europe the layer of super-cooled water drops often lies between heights of 5,000 and 10,000 feet and the shock wave from a hail cannon reaches a height of about 6,000 feet, so that the hail shooting may have some effect. In very severe storms the super-cooled layer extends above 10,000 feet and there is no shock effect.

Hail shooting was first tried in the seventeenth century in the French wine district of Beaujolais, but its use did not become general until near the end of the nineteenth century. In the heyday of hail shooting 10,000–20,000 shots were sometimes fired in a single storm. The practice is now decreasing, but is still in use in some places. The decline may be attributed to the fact that while the cost is certain the benefit is uncertain.

Rockets bursting at 3,000–4,000 feet have sometimes been used instead of cannon, but they are more costly and their effect has not been systematically investigated. Col. Ruby states that they are especially effective against hail-bearing tornadoes. The latest development along these lines is the bombing of the super-cooled layers by aircraft. Rockets were released from an aircraft into the super-cooled layer during a hailstorm in July

1937 and the hail ceased, but more experiments will be necessary before any real effect can be regarded as proven.

The second method of combating hailstorms is the "electric niagara." This consists of a group of high masts erected on hill-tops and well earthed, the theory being that these conductors would dissipate the difference of potential between earth and cloud which accompanies a thunderstorm. A two-year investigation, however, failed to show that electric niagaras had any effect at all on the precipitation of hail.

The third method in use is the ionisation of the air. Positive ions from radio-active material are directed upwards by a positively charged ball, the idea being that they will enter the ascending current of a hailstorm and in some way interfere with the development of hail. Some of these instruments have been installed, but it is not yet known whether they have any effect. Similar ideas such as radio-active rockets and bombs have been suggested, but not tried out.

The difficulty in all these operations is that the phenomena are on so great a scale that the cost of changing the course of nature may exceed the damage to be feared if nature is left alone, so that they are not economically sound. Moreover, it is always difficult to prove that the result obtained would not have followed in any case without human intervention.

## PROTECTION FROM LIGHTNING

Damage and destruction by lightning are due mainly to the sudden intense heat caused by the passage of the discharge through poorly conducting materials. The thermal expansion ruptures brick, concrete and similar materials and the heat sets fire to anything inflammable; fires are also caused by the discharge jumping gaps between two conductors. Dislocation of delicate electrical apparatus is a different effect, caused by the sudden surge of current.

The principle of the protection of structures against lightning is to provide the discharge with a safe and easy passage to earth. Since metals are the best conductors, lightning rods are made of metal, and the highest point should be connected to earth by at least two widely separated conductors, which should be as straight as possible. Sharp bends are especially to be avoided, as lightning is always ready to take short cuts. For the same

reason any large metal objects in the building, especially those within 6 feet of the lightning conductor, should be connected with the latter, or earthed, or both, to prevent side-flashes.

The highest point of a lightning conductor is the apex of a "cone of protection," which is an imaginary cone with a vertical axis, extending to the ground like a tent. All points within the cone are supposed to be protected by the lightning conductor, but there is some doubt about the ratio which the radius of the base bears to the height. The Washington Bureau of Standards "Code for Protection against Lightning" (1945) states that the radius of the base of the cone is from two to four times its height. R. H. Golde (1946) quotes a number of cases in which buildings were struck at points within the 2:1 cone, but he states that these were weak flashes which did little direct damage. The ratio of the radius of the cone of protection to its height increases with the strength of the flash.

The protective ratio also decreases with the height of the conductor. This is because the precise point to be struck is not determined until the leader stroke is about 50 feet from the ground, *i.e.* below the tops of high towers, and at this level it may turn aside and strike sideways. The lowest protective ratios observed, 1·1:1, were in experiments in Russia with earthed balloons when the latter were at a height of 900 metres (2,950 feet). Golde also states that the protective ratio of an earthed horizontal wire is less than 2:1 and probably less than 1·5:1.

As the leader stroke approaches the ground there is a rapid flow of electricity through the earth to the point immediately beneath it, and this earth-current may be sufficiently strong to cause damage. Hence it is desirable to earth the conductor in at least two points on either side of the building to be protected. The best earth is a metal conductor, such as a water-pipe which can carry the earth-current safely from a considerable distance.

Although weak lightning flashes may sometimes strike buildings protected by outside conductors, they rarely penetrate the interior. Interior damage is generally caused by induction, due to the electrical installation being too near the conductor, and is usually confined to burning out a few lamps and blowing fuses. In unprotected buildings, on the other hand, the electric wiring often offers the path of least resistance to earth. The greatest danger is from aerial conductors entering the building;

Ch. Forel (1939) considers that currents in such wires, due either to direct striking or to induction, caused most of the damage reported in protected buildings in Switzerland. He recommends that where practicable aerial wires near the building should be replaced by subterranean cables of large capacity.

## PROTECTION AGAINST FROST

Frost, while especially feared by farmers and fruit growers, also interferes with many other activities. Frosts are of two kinds, general frosts caused by wide, deep currents of air below freezing point sweeping over the whole countryside, and local frosts due to radiation from the ground on calm, clear nights. The first type of frost, which comes with north-east or east winds in Britain and north or north-west winds in North America, is often termed a "black frost" because the air is dry and there is little or no formation of hoar frost. Such frosts may continue for several days and nights, and very little can be done to counteract them.

The second type, radiation frost, is due to the loss of heat from the ground to the air and sky on clear nights with calm air or light winds. The ground chills the air above it and the layer of cold air flows down the slopes and accumulates in the hollows and narrow valleys. The air is usually cooled below the temperature at which it is saturated, and moisture is deposited on the ground and vegetation, but since these are below freezing point the deposit takes the form of hoar frost; consequently a radiation frost is often termed a "white frost."

Various methods of combating radiation frost have been tried. These are described by R. Bush (1946), and in very great detail by O. W. Kessler and W. Kaempfert (1940). They may be classified as:—

(1) Preventing loss of heat by radiation.
(2) Stirring the air to bring down heat from above.
(3) Diverting the flow of cold air.
(4) Heating the air by burning fuel or spraying with warm water.

*Preventing loss of heat by radiation.*—Since the cause of frost is the radiation of heat from the ground, crops, etc., the fall of temperature can be minimised by intercepting the heat radiated

and returning it to the ground. This can be achieved by covering the crop to be protected. The covering may take the form of a layer of loose straw, cones or ridges of straw, etc., or one of the various types of glass "cloches." These may keep the temperature 3–5° F. above that of freely exposed objects.

On a somewhat larger scale protection can be given by the erection of a temporary "roof" resting on poles a few feet above the ground. The construction can be quite light, but there must be flaps which can be dropped on the up-wind side to prevent cold air from drifting underneath the cover. This form of protection is sometimes used on a small scale to prevent the freezing of cement in process of setting.

It has long been known that serious radiation frost does not occur on cloudy nights. From this comes the idea of forming an artificial "cloud" by burning some form of smoky fuel or by one of the various chemical smokes available—the nature of the particles does not make much difference. A really dense cloud can maintain a temperature 4–7° F. above that in neighbouring areas not covered by the cloud. At one time this method was in great favour, but it is now being abandoned. A concentration of smoke dense enough to be effective is also dense enough to be a nuisance, and even harmful; in the U.S.A. the amount of smoke which may be emitted by a heater is now limited by law. Further, on sloping ground the flow of cold air from higher levels can cut under the smoke cloud, which then loses most of its protective value.

Since water vapour absorbs radiation and re-radiates it, the suggestion has been made that the addition of water vapour to the air, for example by burning damp straw, would cut down the loss of heat by radiation. The effect of water vapour, however, does not depend entirely or even mainly on the amount in the lowest layer of air, but on the whole mass of water vapour in the atmosphere above the locality. There are various other difficulties, and it is very doubtful if the gain of temperature by this means can exceed 1° F.

The statement is sometimes made that a smoke cloud or similar protective cover *raises* the temperature by so many degrees. This is incorrect; all it can do is to decrease the rate of fall.

*Stirring the air.*—In a radiation frost there is an "inversion" of temperature. The air is coldest near the ground and becomes

warmer at higher levels; at a height of 50 feet above a level plain it may be several degrees higher than at ground level. If this warm air could be brought down to ground level the result would be an appreciable rise of temperature. This method of frost prevention is theoretically possible on a level plain or gentle slope, but not in a frost hollow where the layer of freezing air is much deeper. There is another advantage: in still air radiating surfaces fall below the air temperature, but in moving air this difference is minimised. Experiments are being tried, but so far the results are not conclusive, though there has been a slight rise of temperature in the immediate neighbourhood of the ventilator. According to the *Daily Telegraph* for 16th May 1949 investigations with horizontal fans were being carried on near Silsoe, Beds and Royston, Herts, for prevention of frost in orchards.

*Diverting the flow of cold air.*—Any obstacle placed across the flow of cold air on a sloping hill-side results in a local accumulation on the up-slope side, and makes a small "frost-hollow." A high hedge, wall or row of trees on the slope *below* a garden or building therefore increases the risk of frost, unless a gap is cut in the barrier to allow the cold air to drain away; a similar obstacle on the slope above holds back the cold air and decreases the risk of frost. This effect is most noticeable where the hill slope is interrupted by a terrace or slight hollow. A hedge planted obliquely down the hill can deflect the flow of cold air to one side. The obstacle must extend down very nearly to ground level, for the air is coldest near the ground and can easily penetrate a belt of trees with trunks bare to a height of 10 feet or so. Where for any reason walls or hedges are impracticable, or while hedges are growing, temporary screens may be hung on posts in strategic positions when there is a risk of frost. This method of protection does not decrease the loss of heat; it merely re-distributes the cold air to places where it can do less damage.

The effect of gaps in an obstacle is quite remarkable. It has been noticed, for example, that where a railway embankment follows the contours of a slope, but is pierced by an opening for a road, on the up-slope side the height to which trees are frosted is lower on either side of the opening than farther away, while on the down-slope side there is an area of frost opposite the opening, but none on either side.

In planning an orchard, garden, group of storehouses, etc., in which it is necessary to minimise the risk of frost, much can be done by careful siting and arrangement after study of the local air drainage. On the other hand, as Bush points out, it should be possible to make use of cold air flows to keep goods cool in summer by building storehouses across the night flow of cold air, preferably below ground, opening them by night and closing them by day.

*Heating the air.*—The most effective means of protecting a garden or orchard against frost is by actually warming the air. Any form of heating can be used, the most practicable being oil, coal or peat. The choice depends partly on the relative cost of the fuel on the spot and partly on the labour available, since oil burners can be arranged to burn all night, while coal stoves require more frequent attention. Efficient heaters can maintain a temperature 7–10° F. above that of unprotected areas. A report on the efficiency of different types of heater has been prepared by R. Gallay and P. Darbre (1948).

The arrangement of the heaters is a matter of considerable importance. A single source of great heat has little effect because the heated air breaks right through the inversion and is lost in the upper air. The effect to be aimed at is a local circulation of the air within the inversion layer, so that the heat is not lost. The air over the heater rises and is replaced by air drawn in at ground level on all sides, but at a moderate height the heated air is drawn sideways and down to replace the surface air. This effect is best obtained by a number of small heaters. For normal situations Bush recommends fifty heating pots to the acre, which is about one per hundred square yards, the number to be increased in bad frost hollows. Kessler and Kaempfert recommend 1 to 60 square yards. Burners providing 10,000 kcal./hour (about 40,000 B.T.U. per hour) spaced at the rate of 1 to 60 square yards can raise the general air temperature by 6–8° F. Actually, burners should not be equally spaced; in still weather they should be closer on the edges than in the middle, and if there is any breeze they should be closer on the windward side.

When the frost is caused by the flow of cold air down slopes a "barrage" of hot air has been tried. This takes the form of either a row of heaters across the slope or a gently inclined iron tunnel of inverted U-shape, in which air heated initially to a

very high temperature at the lower end flows up the slope of the tunnel, warming the upper surface of the iron.

Oil burners are very popular in the U.S.A., where oil fuel is plentiful and cheap. Even with these advantages, however, heating is expensive and uncertain. Not infrequently the cost of the fuel is greater than the value of the crop saved.

Where facilities are available, either from permanent standpipes or from water-carts, spraying with water is said to be effective. Water acts in three ways: first, the temperature and especially the heat content of the water is higher than that of the air; secondly, if the water freezes, the release of latent heat checks the fall of temperature at just under 32° F., which may not be low enough to cause damage; thirdly, the conductivity of the soil is increased by wetting so that more heat escapes from the sub-soil to warm the air above. Of these the second effect is the most important. Kessler and Kaempfert state that a suitable amount of water to release is 5 litres per square metre per hour, equivalent to about 5½ quarts per square yard. Too much water swamps the ground. Experiments in Germany resulted in the temperature being held at 31° F., but the method has not yet been sufficiently tried out to say whether it is really efficient.

*Forecasting frosts.*—In view of the cost in fuel or labour or both of anti-frost measures, it is essential that they should only be taken when really necessary. This involves forecasting the occurrence of frost a few hours ahead. Warnings of the risk of frost are included in the official weather forecasts, but in conditions favouring radiation frost it is the local topography which determines whether any particular spot will be in a danger area. Various methods have been devised for making local forecasts.

The simplest method is based only on temperature. If, fairly early in the night, the thermometer falls below 35° F., frost is probable before morning. There are a number of devices available which ring a warning bell when the temperature falls to 35° F. (or any other level pre-selected as dangerous). These may consist of a mercury thermometer with two contacts sealed into the glass, apparatus depending on the different rates of contraction of two rods of different metal, or other similar arrangements. If some of these are placed in the most dangerous spots and wired to the house, early warning is given.

Even on a cloudless night the rate of cooling depends very

much on the humidity of the air. Owing to the latent heat liberated when dew or hoar frost is formed, the night minimum rarely falls much below the dew-point—probably 4° F. is a fair allowance only exceeded in exceptional conditions. Consequently an idea of the probable night minimum can be obtained by reading a psychrometer consisting of a dry-bulb and wet-bulb thermometer, finding the dew-point from tables which are often supplied with the instrument, and subtracting 4° F. (If the dew-point is below 32° F. hoar frost will be formed, and it should then be termed the "frost-point".)

Temperature and humidity do not exhaust the list of factors affecting the risk of frost. Cloud is obviously important; on a cloudy night frost is unlikely if the temperature at sunset is not below 38° F. Other things being equal, frost is less probable if the soil is wet than if it is dry. Wind speed is important; a strong wind breaks up the surface layer of cold air and prevents it from drifting into the valleys. Wind direction has to be considered; even a moderate breeze blowing against the slope of the ground minimises the risk of frost. Finally, the length of the night is an obvious factor; starting with the same temperature at sunset, a lower minimum is to be expected on a winter night than on a night in spring, the difference in western Europe being roughly 1° F. for every 1½ hours difference in the length of the night from sunset to sunrise. A discussion of the effect of humidity, state of soil and length of night was given by L. Dufour (n.d.); who calculated the following figures for the fall of temperature over dry soil at Brussels between sunset and sunrise:—

| Relative humidity at sunset % | 100 | 80 | 60 | 40 |
|---|---|---|---|---|
| Probable fall of temperature: ° F. | | | | |
| Night of 16 hours . . | 22 | 23 | 25 | 29 |
| Night of 10 hours . . | 18 | 19 | 21 | 24 |

These figures for relative humidities of 100 and 80 per cent. at least seem to me to be improbably high, but local topography dominates the variation of temperature at night to such an extent that general tables are not of much use for special cases. Experience on the spot, aided by keeping records of self-registering maximum and minimum thermometers and dry- and wet-bulb thermometers read at a fixed hour each evening is likely to be the best guide.

"WIND-BREAKS"

The use of rows of trees as a protection against wind in open country is a very old practice; if properly managed they are also ornamental and a useful source of timber and fuel. In recent years a number of investigations have been carried out which show that this method of protection is effective. The most comprehensive were by W. Nägeli (1943, 1946) in various parts of Switzerland where wind-breaks are erected as a protection against the strong winds which sweep up the valleys by day. Investigations in Russia were carried out by B. A. Bodroff (1935). For a discussion of the use of wind-breaks in a sub-tropical country see E. J. Kelly-Edwards (1945). These and other investigations all show similar results. Practical hints on growing wind-breaks are given by A. A. Pardy (1946).

The best form of wind-break is a belt of mixed trees five to ten yards wide, which contains at least three rows of trees and is moderately dense. Spruce, which was formerly used extensively in Europe, is too dense while young, and as it ages it tends to develop bare trunks beneath the crowns, allowing the wind to sweep through near the ground. Deciduous trees alone are too permeable in winter when they lose their leaves. The best compromise is a mixture of the two, which should be managed in such a way as to form a barrier of equal permeability from the ground upwards. The height should be as uniform as possible, except at the ends or at any unavoidable gaps, where the level should be tapered off to avoid the formation of turbulent eddies. Wind-breaks should, of course, be planted at right-angles to the locally prevailing winds.

Four zones may be distinguished in the variation of wind speed on either side of a wind-break. In Fig. 34 the horizontal scale represents horizontal distances up-wind and down-wind from the barrier, expressed as multiples of the height of the latter. The vertical scale represents wind speed as a percentage of the speed in the open plain away from all obstacles. Up-wind from the barrier (zone A) the wind speed begins to decrease at a distance equal to about six times the height of the barrier. Immediately behind the latter (zone B) the wind speed falls to a very low figure of 15–40 per cent. of the free wind, the lowest speed being at an average distance of three or four times the height. The denser the barrier, the nearer the minimum is

to it, the smaller the wind speed, and the steeper the following rise. The third zone, C, extending from about six to about twelve times the height, is that of rapid recovery of wind speed to a value of 75–80 per cent. of that in the open. Here the wind is often turbulent, the turbulence being greater the steeper the rise, *i.e.* the denser the barrier. The turbulence brings down-drafts of air which sometimes flatten crops, and for this reason too dense a wind-break is a disadvantage. Finally, in zone D the wind gradually returns to its undisturbed condition; the

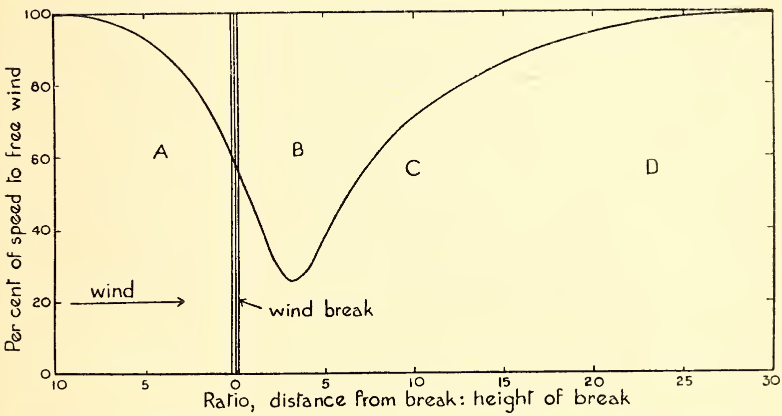


Fig. 34.—Wind speed up- and down-wind from a wind-break.

latter is usually reached at a distance of twenty-four to thirty times the height.

These ratios appear to be almost constant, irrespective of the height of the wind-break and the strength of the wind. For example, a belt of trees 50 feet high protects five times as large an area as a hedge 10 feet high, and if at any spot a wind of 20 m.p.h. is reduced to 10 m.p.h., a wind of 10 m.p.h. will be reduced to 5 m.p.h. (Bodroff, however, thinks that the sheltering effect increases with the strength of the wind.) If the wind is very turbulent the reduction factor is smaller. This probably accounts for the fact that in a succession of similar wind-breaks the second and subsequent ones are sometimes less effective than the first. According to Nägeli, the protection extends to and slightly above the level of the top of the wind-break, decreasing little with height above the ground, but I should expect the recovery to open conditions to be rather more rapid in the upper levels.

If a system of wind-breaks is being planned, it follows that they should be planted at distances apart of about twenty-five times their expected height. Thus, if they are intended to grow to 50 feet they should be not more than a quarter of a mile apart. Allowing for each belt to monopolise a strip some 10 yards wide, this means using 2–2½ per cent. of the ground area for wind-breaks. The protection from wind and decreased evaporation makes the sacrifice of this amount of ground profitable for agriculture in windy districts.

The effect of a wind-break is to slow up slightly the whole mass of air passing through and over it, but this is compensated to some extent by increased wind speed at the ends of the barrier and probably also at some height above it. At the ends and behind any gaps of appreciable width the average wind speed may be 20 per cent. higher than in the open, but this local increase does not persist far down-wind. In designing wind-breaks care must be taken not to place them in such positions that they hold up flows of cold air and so form frost-pockets in places where frost can cause damage (see p. 79).

## CONCLUSION

As previously stated, the whole problem of controlling the weather is bound up with the supply of energy and the location of points of attack. The mechanical energy of a large mass of rapidly moving air, such as constitutes a cyclone or barometric depression, is so great that the cost of the power necessary to exert any appreciable effect on it would be prohibitive. R. Corless (1930) computed that in the severe storm of 12th January 1930 the energy crossing a vertical section of the atmosphere of one square mile (*i.e.* crossing a line one mile long up to a height of one mile) near the Channel Islands was about 100,000,000 kilowatts per second. If this storm could have been produced by expending electricity the cost at one halfpenny per unit would have been £750,000,000 per hour. The thermal capacity of a large mass of air, and the electrical energy of a thunderstorm, are similarly too large for human efforts to have much effect on them. The only possibilities of modifying weather at a relatively small cost lie either in attacking the chain of cause and effect at its weakest link, as in rain-making and hail-shooting, or in gently guiding the natural phenomena

into channels where they can do the least harm, as by the use of lightning conductors.

If by the development of atomic power the supply of available energy at small cost is increased many hundredfold, the case will be different, and large scale control of the weather may become possible. One such possibility, breaking up the Arctic ice cap with atomic bombs in order to decrease the storminess of the North Atlantic regions, has already been canvassed in the Press. The results of such action, however, would be very complicated and might as easily be disastrous as beneficial. If civilisation endures, mastery of weather will probably come, but not without much thought, trial and tribulation.

# APPENDICES

# APPENDIX I

## CLIMATIC TABLES

THE following pages give climatic data for a representative collection of places. They are mostly based on the official publications of the countries concerned, and have been collected over many years; some of them appeared in my earlier book *Climate*. They should, of course, have included information about the hours of observation and the period covered, but this would have doubled the space required without being of much help to the non-meteorologist. As temperatures are given to the nearest whole degree and rainfall to the nearest tenth of an inch, which are sufficient approximations for the purpose of the book, the omission is of less consequence than if the figures had been set out more minutely.

Most of the headings are self-explanatory, but a word is required about "Mean Annual Maximum (or Minimum) Temperature." The Mean Annual Maximum is obtained by finding the highest daily maximum temperature in each of a number of years and taking the average. It represents the highest temperature to be expected in an average year, and will be exceeded in about one year in two. The Mean Annual Minimum is obtained in a similar way from the lowest daily minimum temperatures in each year. These are among the most valuable data of applied climatology.

Humidity is represented by the Relative Humidity, as nearly as possible the mean for the twenty-four hours. From this and the mean air temperature any other measure of humidity can be found, such as water-content or dew point. These can be calculated roughly from the figures in Appendix II, or more exactly from detailed tables such as the "Hygrometric Tables" of the Meteorological Office, London (1940).

I had intended to include frequencies of days of snow and fog, but the available data proved to be too scanty and not comparable for different stations. References to snow and fog have therefore been included only in the "thumb-nail sketches" or "Climatic character." These, on the right of the climatic

tables, are something of an experiment. They have been obtained as follows:—

Starting with temperature as the basis, we can first of all classify the different places into:—

*Hot.*—All months have a mean temperature exceeding 65° F.

*Warm.*—At least one month below 65°, no month below 40°; annual range exceeds 30° F.

*Warm equable.*—At least one month below 65°, no month below 40°; annual range less than 30° F.

*Warm extreme.*—At least one month above 65°, at least one month below 40° F.

*Very extreme.*—Difference between warmest and coldest month exceeds 50° F.

*Cool equable.*—All months below 65°, no month below 27° F.

*Cool extreme.*—At least one month above 50°, at least one month below 27° F.

*Cold.*—All months below 50°, at least one month below 27° F.

The effectiveness of rain depends on the temperature at which it falls. An inch of rain dries off very quickly in a hot summer, but in a cold winter it has a lasting effect on soil, roads, etc. We may roughly classify climate according to the way in which the annual rainfall $R$ in inches is related to the mean annual temperature $T$ in ° F., and the season at which rain falls, as follows:—

| | Dry | Moderately Rainy | Rainy | Very Rainy |
|---|---|---|---|---|
| Rainfall at all seasons | R below T/2–12 | T/2–12 to T–25 | T–25 to 2T–50 | Above 2T–50 |
| Rainfall mainly in winter | R below T/2–15 | T/2–15 to T–30 | T–30 to 2T–60 | Above 2T–60 |
| Rainfall mainly in summer | R below T/2–10 | T/2–10 to T–20 | T–20 to 2T–40 | Above 2T–40 |

Where the mean annual temperature is less than 40° F., evaporation is generally so small that the amount of rainfall ceases to have much meaning, especially as in winter it falls entirely as snow. For convenience in such cases, we describe a rainfall of less than 10 inches as a dry climate and one of 10 to 20 inches a year as snowy. An annual rainfall of less

than 5 inches is described as very dry and one of less than 2 inches as nearly rainless.

If the mean annual relative humidity exceeds 80 per cent., the climate may be described as humid; if it is less than 50 per cent. as arid. Similarly, if the mean annual number of days of snow, thunderstorms or fog exceeds 50 the climate may be described as snowy, thundery or foggy, and if the number exceeds 75 these conditions are extreme.

London (Richmond) has a mean temperature of 63° F. in July and 41° in January, and is cool equable. The rainfall is well distributed and amounts to 24 inches a year with a mean annual temperature of 50° F., so that the climate is moderately rainy. At Washington, D.C., the mean temperature ranges from 77° in July to 33° F. in January (warm extreme), annual mean 55°, rainfall 42 inches well distributed (rainy). At Rangoon (Burma) the lowest monthly mean temperature is 77° (hot); annual mean 81°, rainfall 99 inches mainly in summer (rainy, dry winter).

# APPENDIX I

## Climatic Tables

| Place. | Lat. | Long. | Height | Mean Temperature. | | | Mean Annual. | | Relative Humidity. | | Rainfall. | | | Days of Rain. | Climatic character. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Year. | Jan. | July. | Max. | Min. | Jan. | July. | Year. | Wettest Month. | Driest month. | | |
| *England and Wales*— | | | feet. | ° F. | ° F. | ° F. | ° F. | ° F. | % | % | inches. | inches. | inches. | | |
| Birmingham | 52°29′ N. | 1°56′ W. | 535 | 49 | 39 | 61 | 84 | 21 | 86 | 71 | 28·4 | Dec. 3·0 | Feb. 1·9 | 170 | Cool equable, rainy, foggy. |
| Cardiff | 51°28′ N. | 3°10′ W. | 202 | 49 | 41 | 61 | 82 | 21 | 89 | 76 | 41·4 | Dec. 5·0 | May 2·5 | 196 | Cool equable, rainy. |
| Dover | 51° 7′ N. | 1°19′ E. | 22 | 50 | 40 | 61 | 81 | 21 | 83 | 73 | 27·7 | Oct. 3·8 | May 1·6 | 178 | Cool equable, rainy. |
| Falmouth | 50° 9′ N. | 5° 3′ W. | 240 | 51 | 44 | 61 | 75 | 29 | 83 | 79 | 43·6 | Dec. 6·3 | May 2·2 | 207 | Cool equable, rainy. |
| London (Kew) | 51°28′ N. | 0°19′ W. | 18 | 50 | 41 | 63 | 85 | 19 | 85 | 69 | 23·8 | Oct. 2·7 | April 1·5 | 167 | Cool equable, mod. rainy. |
| Manchester | 53°29′ N. | 2°13′ W. | 190 | 50 | 41 | 61 | — | — | (86) | (64) | 35·4 | Aug. 3·9 | April 2·1 | 196 | Cool equable, rainy, foggy. |
| Portsmouth | 50°48′ N. | 1° 6′ W. | 15 | 51 | 41 | 63 | 82 | 24 | 89 | 75 | 27·7 | Oct. 3·7 | April 1·6 | 163 | Cool equable, mod. rainy. |
| Tynemouth | 55° 1′ N. | 1°25′ W. | 108 | 48 | 41 | 59 | 78 | 20 | 85 | 79 | 24·5 | Oct. 3·0 | April 1·4 | 179 | Cool equable, rainy. |
| Yarmouth | 52°35′ N. | 1°43′ E. | 5 | 50 | 41 | 62 | 80 | 22 | 89 | 80 | 24·5 | Oct. 2·9 | April 1·5 | 183 | Cool equable, mod. rainy. |
| *Scotland*— | | | | | | | | | | | | | | | |
| Aberdeen | 57°10′ N. | 2° 6′ W. | 79 | 47 | 39 | 57 | 76 | 15 | 82 | 78 | 29·5 | Dec. 3·2 | June 1·7 | 214 | Cool equable, rainy. |
| Edinburgh | 55°55′ N. | 3°11′ W. | 441 | 47 | 39 | 57 | — | — | (82) | (70) | 26·5 | Aug. 3·4 | April 1·5 | 189 | Cool equable, rainy. |
| Lerwick | 60° 9′ N. | 1° 8′ W. | 156 | 45 | 40 | 53 | 65 | 22 | 86 | 86 | 38·0 | Dec. 4·8 | June 1·8 | 260 | Cool equable, rainy. |
| Stornoway | 58°11′ N. | 6°21′ W. | 79 | 47 | 41 | 56 | 72 | 21 | 88 | 85 | 47·3 | Dec. 5·9 | June 2·2 | 263 | Cool equable, very rainy. |
| *Ireland*— | | | | | | | | | | | | | | | |
| Belfast | 54°35′ N. | 5°36′ W. | 61 | 48 | 40 | 59 | — | — | (86) | (73) | 37·8 | Dec. 4·2 | April 2·4 | 231 | Cool equable, rainy. |
| Cork (Roches Point) | 51°47′ N. | 8°15′ W. | 22 | 51 | 45 | 60 | 73 | 27 | 90 | 85 | 41·9 | Dec. 5·3 | May 2·4 | 212 | Cool equable, rainy. |
| Dublin | 53°22′ N. | 6°21′ W. | 155 | 48 | 41 | 59 | 78 | 16 | 87 | 78 | 27·6 | Aug. 3·2 | April 1·8 | 218 | Cool equable, rainy. |
| EUROPE. | | | | | | | | | | | | | | | |
| *Albania*— | | | | | | | | | | | | | | | |
| Durazzo | 41°19′ N. | 19°28′ E. | 23 | 61 | 47 | 77 | 92 | 26 | 77 | 68 | 42·5 | Nov. 8·4 | July 0·5 | 97 | Warm rainy. |
| *Austria*— | | | | | | | | | | | | | | | |
| Innsbruck | 47°16′ N. | 11°24′ E. | 1,970 | 47 | 26 | 65 | 88 | −1 | 84 | 73 | 33·6 | July 5·2 | Jan. 1·6 | 139 | Cool extreme, rainy, v. foggy. |
| Vienna | 48°15′ N. | 16°22′ E. | 666 | 49 | 30 | 67 | 91 | 7 | 79 | 62 | 25·6 | July 3·1 | Feb. 1·3 | 159 | Warm extreme, rainy. |
| *Belgium*— | | | | | | | | | | | | | | | |
| Brussels | 50°48′ N. | 4°22′ E. | 328 | 49 | 35 | 63 | 88 | 13 | 90 | 79 | 28·8 | Aug. 2·9 | April 1·8 | 195 | Cool equable, rainy, foggy. |
| *Bulgaria*— | | | | | | | | | | | | | | | |
| Sofia | 42°42′ N. | 23°20′ E. | 1,804 | 49 | 26 | 68 | 96 | 2 | 82 | 63 | 25·1 | May 3·4 | Dec. 1·4 | 113 | Warm extreme, mod. rainy, foggy. |
| *Cyprus*— | | | | | | | | | | | | | | | |
| Nicosia | 35°11′ N. | 33°32′ E. | 499 | 65 | 48 | 82 | 106 | 30 | 82 | 65 | 14·8 | Dec. 3·0 | July, Aug. 0·1 | 52 | Warm extreme, dry. |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Czecho-Slovakia*— | | | | | | | | | | | | | | | |
| Brünn | 49°11′ N. | 16°33′ E. | 680 | 47 | 26 | 66 | 91 | 2 | 93 | 71 | 20·8 | July 2·8 | Feb. 0·9 | 150 | Warm extreme, mod. rainy. |
| Karlsbad | 50°13′ N. | 12°53′ E | 1,398 | 45 | 30 | 64 | 89 | 3 | 84 | 69 | 24·0 | July 3·1 | Mar. 1·1 | 184 | Cool rainy. |
| Prague | 50° 5′ N. | 14°25′ E. | 662 | 48 | 30 | 66 | 91 | 3 | 81 | 65 | 19·3 | June 2·8 | Feb. 0·8 | 150 | Warm extreme, mod. rainy, very foggy. |
| *Denmark*— | | | | | | | | | | | | | | | |
| Copenhagen | 55°41′ N. | 12°33′ E. | 43 | 46 | 32 | 62 | 83 | 11 | 88 | 75 | 20·8 | Aug. 2·6 | Jan. 1·3 | 176 | Cool equable, rainy. |
| *Estonia*— | | | | | | | | | | | | | | | |
| Tallinn (Revel) | 59°26′ N. | 24°48′ E. | 146 | 40 | 22 | 61 | 83 | −9 | 88 | 78 | 23·8 | Aug. 3·6 | Mar. 1·1 | 176 | Cool extreme, rainy, snowy, foggy. |
| Tartu (Dorpat) | 58°23′ N. | 26°43′ E. | 244 | 40 | 20 | 63 | 87 | −14 | 90 | 73 | 23·1 | July 3·3 | Mar. 1·1 | 186 | Cool extreme, rainy, v. snowy. |
| *Faroes*— | | | | | | | | | | | | | | | |
| Thorshavn | 62° 2′ N. | 6°45′ W. | 82 | 43 | 38 | 51 | 63 | 16 | 83 | 86 | 56·2 | Dec. 6·6 | June 2·5 | 281 | Cool equable, v. rainy, foggy. |
| *Finland*— | | | | | | | | | | | | | | | |
| Helsinki | 60°10′ N. | 24°57′ E. | 38 | 40 | 23 | 62 | 82 | −11 | 88 | 73 | 27·6 | Aug. 3·3 | Mar. 1·7 | 183 | Cool extreme, rainy, foggy. |
| Oulu (Uleaborg) | 65° 2′ N. | 25°28′ E. | 25 | 35 | 16 | 60 | 84 | −23 | 89 | 69 | 21·1 | Aug. 2·8 | Mar. 1·0 | 154 | Cool extreme, rainy. |
| *France*— | | | | | | | | | | | | | | | |
| Bordeaux | 44°50′ N. | 0°42′ W. | 157 | 54 | 41 | 68 | 96 | 20 | 86 | 66 | 30·3 | Oct. 3·4 | Aug. 1·9 | 200 | Warm equable, rainy. |
| Cherbourg | 49°39′ N. | 1°38′ W. | 30 | 52 | 44 | 62 | 82 | 25 | 83 | 79 | 40·0 | Dec. 5·5 | June 1·7 | 172 | Warm equable, rainy. |
| Lyons | 45°44′ N. | 4°55′ E. | 643 | 51 | 35 | 68 | 94 | 11 | 81 | 61 | 28·6 | Oct. 3·3 | Jan. 1·3 | 152 | Warm extreme, mod. rainy. |
| Marseilles | 43°18′ N. | 5°23′ E. | 146 | 57 | 43 | 72 | 92 | 23 | 68 | 54 | 22·5 | Oct. 4·0 | July 0·6 | 72 | Warm, mod. rainy. |
| Nice | 43°43′ N. | 7°18′ E. | 1,115 | 56 | 44 | 71 | 90 | 27 | 63 | 65 | 31·6 | Oct. 5·7 | July 0·9 | 102 | Warm equable, rainy. |
| Paris | 48°49′ N. | 2°29′ E. | 164 | 51 | 38 | 65 | 92 | 16 | 86 | 73 | 22·1 | June, Oct. 2·2 | Feb. 1·3 | 174 | Warm equable, mod. rainy, v. foggy. |
| Strasbourg | 48°35′ N. | 7°46′ E. | 456 | 50 | 34 | 66 | 93 | 9 | 84 | 66 | 22·5 | July 3·0 | Jan. 1·0 | 161 | Warm extreme, mod. rainy. |
| Ajaccio (Corsica) | 41°55′ N. | 8°44′ E. | 53 | 61 | 49 | 74 | — | — | 81 | 77 | 26·1 | Nov. 4·6 | July 0·2 | 92 | Warm equable, mod. rainy. |
| *Germany*— | | | | | | | | | | | | | | | |
| Aachen | 50°47′ N. | 6° 4′ E. | 554 | 49 | 35 | 63 | 90 | 12 | 83 | 73 | 33·4 | July 3·6 | Feb. 2·1 | 194 | Cool equable, rainy, foggy. |
| Berlin | 52°27′ N. | 13°18′ E. | 187 | 47 | 32 | 64 | 91 | 6 | 85 | 69 | 23·5 | July 3·2 | Feb. 1·3 | 169 | Intermediate, mod. rainy. |
| Breslau | 51° 7′ N. | 17° 5′ E. | 482 | 48 | 30 | 65 | 90 | 1 | 83 | 67 | 22·4 | July, Aug. 3·1 | Jan. 1·1 | 167 | Intermediate, mod. rainy. |
| Frankfurt-am-Main | 50° 7′ N. | 8°40′ E. | 338 | 49 | 34 | 65 | 91 | 9 | 85 | 69 | 24·3 | Aug. 3·0 | Feb. 1·4 | 160 | Intermediate, mod. rainy. |
| Hamburg | 53°33′ N. | 9°58′ E. | 66 | 47 | 33 | 63 | 85 | 10 | 89 | 76 | 28·9 | July 3·4 | April 1·8 | 195 | Cool equable, rainy, v. foggy. |
| Leipzig | 51°18′ N. | 12°23′ E. | 371 | 48 | 30 | 65 | 88 | 3 | 89 | 72 | 24·8 | July 3·4 | Jan. 1·4 | 164 | Intermediate, mod. rainy. |
| Munich | 48° 9′ N. | 11°34′ E. | 1,739 | 46 | 29 | 62 | 86 | −1 | 83 | 67 | 34·9 | July 5·1 | Feb. 1·3 | 204 | Cool, rainy. |
| Stuttgart | 48°47′ N. | 9°10′ E. | 876 | 47 | 32 | 64 | 91 | 8 | 83 | 70 | 25·8 | June 3·0 | Feb. 1·2 | 168 | Cool, mod. rainy. |
| *Gibraltar* | 36° 6′ N. | 5°21′ W. | 90 | 64 | 55 | 73 | 93 | 38 | 77 | 71 | 35·1 | Nov. 6·4 | July 0·0 | 85 | Warm equable, mod. winter rain. |
| *Greece*— | | | | | | | | | | | | | | | |
| Athens | 37°58′ N. | 23°43′ E. | 351 | 63 | 48 | 80 | 100 | 29 | 73 | 48 | 15·7 | Nov. 2·8 | July 0·2 | 98 | Warm, dry. |
| Salonica | 40°40′ N. | 22°58′ E. | 98 | 61 | 42 | 79 | 100 | 21 | 74 | 54 | 19·2 | Nov. 2·5 | Aug. 0·9 | 94 | Warm, mod. rainy. |
| Candia (Crete) | 35°20′ N. | 25° 9′ E. | 89 | 66 | 54 | 78 | 99 | 38 | 71 | 60 | 19·2 | Dec. 4·0 | July 0·0 | 69 | Warm, mod. winter rain. |
| *Holland*— | | | | | | | | | | | | | | | |
| Flushing | 51°26′ N. | 3°34′ E. | 19 | 50 | 38 | 62 | 85 | 18 | 88 | 75 | 28·3 | Aug. 3·1 | Feb. 1·6 | — | Cool equable, rainy, foggy. |
| Utrecht | 52° 6′ N. | 5°11′ E. | 10 | 48 | 36 | 62 | 88 | 11 | 89 | 75 | 30·1 | Aug. 3·5 | Feb. 1·8 | 207 | Cool equable, rainy, foggy. |

# Climatic Tables—*continued*

| Place. | Lat. | Long. | Height. | Mean Temperature. Year. | Mean Temperature. Jan. | Mean Temperature. July. | Mean Annual. Max. | Mean Annual. Min. | Relative Humidity. Jan. | Relative Humidity. July. | Rainfall. Year. | Rainfall. Wettest Month. | Rainfall. Driest Month. | Days of Rain. | Climatic Character. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | feet. | ° F. | ° F. | ° F. | ° F. | ° F. | % | % | inches. | inches. | inches. | | |
| *Hungary*— | | | | | | | | | | | | | | | |
| Budapest | 47°31′ N. | 19° 1′ E. | 427 | 51 | 31 | 71 | 92 | 6 | 81 | 60 | 24·0 | June 2·7 | Feb. 1·3 | 139 | Warm extreme, mod. rainy. |
| *Iceland*— | | | | | | | | | | | | | | | |
| Reykjavik | 64° 9′ N. | 21°55′ W. | 16 | 39 | 29 | 53 | 67 | 2 | 90 | 81 | 32·4 | Jan. 3·5 | May 1·9 | 162 | Cool equable, v. rainy. |
| *Italy*— | | | | | | | | | | | | | | | |
| Genoa | 44°25′ N. | 8°55′ E. | 177 | 60 | 46 | 75 | 90 | 28 | 56 | 60 | 51·7 | Oct. 7·9 | July 1·7 | 120 | Warm equable, rainy. |
| Milan | 45°27′ N. | 9°10′ E. | 482 | 56 | 36 | 75 | 96 | 17 | 81 | 58 | 37·3 | Oct. 4·5 | Feb. 2·2 | 120 | Warm extreme, rainy. |
| Palermo | 38° 7′ N. | 13°21′ E. | 234 | 63 | 51 | 76 | 106 | 33 | 76 | 62 | 25·1 | Dec. 3·7 | July 0·2 | 111 | Warm equable, mod. rainy. |
| Rome | 41°54′ N. | 12°29′ E. | 208 | 57 | 44 | 73 | 95 | 26 | 72 | 55 | 26·7 | Oct. 4·1 | July 0·3 | 105 | Warm, mod. rainy. |
| Venice | 45°26′ N. | 12°20′ E. | 82 | 56 | 37 | 76 | 91 | 22 | 80 | 65 | 29·3 | Oct. 3·6 | Jan. 1·6 | 97 | Warm extreme, mod. rainy. |
| *Latvia*— | | | | | | | | | | | | | | | |
| Riga | 56°57′ N. | 24° 6′ E. | 41 | 43 | 25 | 64 | 86 | −6 | 88 | 73 | 25·4 | Aug. 3·5 | Mar. 1·1 | 176 | Cool extreme, rainy, foggy. |
| *Lithuania*— | | | | | | | | | | | | | | | |
| Kaunas | 54°53′ N. | 23°56′ E. | 272 | 44 | 24 | 65 | — | — | 85 | 73 | 23·8 | Aug. 3·6 | Jan. 0·8 | — | Cool extreme, mod. rainy. |
| *Malta* | 35°54′ N. | 14°31′ E. | 231 | 64 | 53 | 77 | 97 | 42 | 77 | 66 | 19·9 | Dec. 3·7 | July 0·0 | 76 | Warm equable, mod. rainy. |
| *Norway*— | | | | | | | | | | | | | | | |
| Bergen | 60°24′ N. | 5°19′ E. | 144 | 45 | 35 | 57 | 79 | 16 | 80 | 79 | 73·2 | Oct. 8·1 | June 3·5 | 222 | Cool equable, v. rainy. |
| Oslo | 59°55′ N. | 10°43′ E. | 82 | 42 | 24 | 63 | 87 | −2 | 85 | 65 | 25·3 | Aug. 3·6 | Feb. 1·3 | 145 | Cool extreme, rainy, snowy. |
| Tromso | 69°39′ N. | 18°58′ E. | 147 | 36 | 26 | 52 | 72 | 6 | 72 | 79 | 40·8 | Sept. 4·7 | May 1·9 | 162 | Cool extreme, v. rainy. |
| *Poland*— | | | | | | | | | | | | | | | |
| Danzig | 54°24′ N. | 18°40′ E. | 36 | 45 | 29 | 63 | — | — | 86 | 74 | 21·7 | July 2·8 | Feb. 1·0 | 179 | Cool, mod. rainy. |
| Lwow | 49°50′ N. | 24° 1′ E. | 1,023 | 45 | 26 | 65 | 88 | −3 | 84 | 70 | 24·1 | July 3·3 | Jan. 1·0 | 161 | Cool extreme, mod. rainy. |
| Warsaw | 52°13′ N. | 21° 2′ E. | 394 | 46 | 25 | 66 | 89 | −4 | 88 | 70 | 21·7 | Aug. 3·4 | Mar. 0·8 | 157 | Cool extreme, mod. rainy. |
| *Portugal*— | | | | | | | | | | | | | | | |
| Lisbon | 38°43′ N. | 9° 9′ W. | 312 | 60 | 51 | 70 | 97 | 36 | 79 | 62 | 27·1 | Nov. 4·2 | July, Aug. 0·2 | 111 | Warm equable, mod. rainy. |
| *Roumania*— | | | | | | | | | | | | | | | |
| Bucharest | 44°25′ N. | 26° 6′ E. | 269 | 48 | 26 | 65 | 98 | −3 | 85 | 55 | 22·8 | June 3·6 | Feb. 1·0 | 107 | Extreme, mod. rainy, foggy. |
| *Spain*— | | | | | | | | | | | | | | | |
| Barcelona | 41°23′ N. | 2° 8′ E. | 136 | 60 | 47 | 74 | 91 | 29 | 70 | 66 | 21·8 | Oct. 3·2 | July 1·0 | 70 | Warm equable, mod. rainy. |
| Cadiz | 36°31′ N. | 6°17′ W. | — | 64 | 54 | 75 | 94 | 37 | 75 | 66 | 23·7 | Dec. 3·9 | July 0·4 | 70 | Warm equable, mod. rainy. |
| Madrid | 40°24′ N. | 3°42′ W. | 2,149 | 57 | 41 | 78 | 103 | 19 | 77 | 38 | 16·6 | Nov. 1·9 | July 0·4 | 95 | Warm extreme, dry. |
| Palma (Balearic Is.) | 39°34′ N. | 2°37′ E. | 75 | 63 | 51 | 77 | 95 | 35 | 75 | 69 | 18·8 | Oct. 3·1 | July 0·4 | 73 | Warm equable, dry. |
| *Sweden*— | | | | | | | | | | | | | | | |
| Haparanda | 65°50′ N. | 24° 9′ E. | 30 | 33 | 12 | 59 | 81 | −27 | 89 | 71 | 18·4 | Oct. 2·2 | April 0·9 | 145 | Cool extreme, rainy, v. snowy. |
| Stockholm | 59°21′ N. | 18° 4′ E. | 146 | 43 | 27 | 62 | 83 | 3 | 84 | 67 | 22·6 | Aug. 3·1 | Mar. 1·1 | 172 | Cool extreme, rainy, snowy. |
| *Switzerland*— | | | | | | | | | | | | | | | |
| Berne | 46°57′ N. | 7°26′ E. | 1,877 | 46 | 28 | 64 | 84 | 8 | 85 | 71 | 37·3 | June 4·5 | Jan. 1·8 | 145 | Cool rainy. |
| Geneva | 46°11′ N. | 6° 9′ E. | 1,329 | 49 | 32 | 66 | 91 | 11 | 86 | 68 | 36·4 | Aug. 4·2 | Jan. 1·9 | 149 | Mod. rainy. |
| Zurich | 47°23′ N. | 8°33′ E. | 1,540 | 48 | 32 | 64 | 87 | 7 | 84 | 72 | 41·3 | June 5·0 | Feb. 2·0 | 157 | Cool rainy. |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Turkey*— | | | | | | | | | | | | | | | |
| Constantinople (Istanbul) | 41° 2′ N. | 28°58′ E. | 246 | 58 | 41 | 74 | 93 | 24 | 79 | 60 | 28·8 | Dec. 4·8 | May 1·1 | 89 | Warm, mod. rainy. |
| *U.S.S.R.*— | | | | | | | | | | | | | | | |
| Archangel | 64°33′ N. | 40°32′ E. | 22 | 32 | 8 | 60 | 81 | −29 | 88 | 74 | 19·6 | Aug. 2·7 | April 0·7 | 171 | V. extreme, mod. rainy, v. snowy, v. foggy. |
| Astrakhan | 46°21′ N. | 48° 2′ E. | −45 | 49 | 19 | 77 | 95 | −14 | 86 | 58 | 6·4 | June 0·7 | Feb. 0·4 | 46 | V. extreme, dry. |
| Leningrad | 59°56′ N. | 30°16′ E. | 16 | 39 | 18 | 63 | 85 | −14 | 87 | 68 | 19·2 | Aug. 2·8 | Mar. 0·9 | 173 | Cool extreme, mod. rainy. |
| Lenkoran | 38°46′ N. | 48°52′ E. | −62 | 58 | 38 | 77 | 91 | 18 | 88 | 72 | 49·3 | Sept. 8·6 | June 0·9 | 99 | Warm extreme, rainy. |
| Moscow | 55°46′ N. | 37°40′ E. | 512 | 40 | 14 | 66 | 87 | −21 | 86 | 71 | 22·4 | July 3·0 | Feb. 1·1 | 169 | V. extreme, rainy, v. snowy. |
| Odessa | 46°29′ N. | 30°44′ E. | 214 | 50 | 27 | 73 | 92 | 1 | 88 | 60 | 15·5 | June 2·1 | Feb. 0·9 | 88 | Warm extreme, mod. rainy. |
| Tiflis | 41°43′ N. | 44°48′ E. | 1,325 | 55 | 32 | 76 | 95 | 6 | 74 | 54 | 19·9 | May 3·2 | Jan. 0·6 | 107 | Warm extreme, mod. rainy. |
| *Jugo-Slavia*— | | | | | | | | | | | | | | | |
| Belgrade | 44°48′ N. | 20° 5′ E. | 453 | 53 | 32 | 73 | 99 | 4 | 83 | 63 | 24·6 | June 2·8 | Feb. 1·3 | 136 | Warm extreme, mod. rainy, foggy. |
| Zagreb | 45°49′ N. | 15°59′ E. | 535 | 52 | 32 | 71 | 93 | 8 | 84 | 65 | 35·4 | Oct. 4·0 | Feb. 1·7 | 140 | Warm extreme, rainy. |
| ASIA. | | | | | | | | | | | | | | | |
| *Aden* | 12°47′ N. | 44°59′ E. | 123 | 83 | 76 | 88 | 103 | 68 | 72 | 63 | 1·8 | Mar. 0·4 | June, July 0·1 | 4 | Hot. nearly rainless. |
| *Afghanistan*— | | | | | | | | | | | | | | | |
| Kabul | 34°30′ N. | 69°18′ E. | 5,895 | 58 | 32 | 79 | — | — | 80 | 51 | 12·9 | April 3·8 | Sept. 0·0 | 25 | Warm extreme, dry. |
| *Arabia*— | | | | | | | | | | | | | | | |
| Bahrein | 26°12′ N. | 50°30′ E. | 18 | 78 | 61 | 91 | 106 | 46 | 77 | 70 | 2·9 | Dec. 0·8 | June, Sept. 0·0 | 7 | Warm equable, v. dry. |
| Jidda | 21°30′ N. | 39°22′ E. | 20 | 81 | 73 | 87 | 105 | 59 | 67 | 67 | 3·1 | Nov. 1·6 | Feb., Oct. 0·0 | 9 | Hot, v. dry. |
| *Baluchistan*— | | | | | | | | | | | | | | | |
| Quetta | 30°10′ N. | 67° 1′ E. | 5,502 | 59 | 40 | 79 | 100 | 15 | 70 | 45 | 10·0 | Feb. 2·0 | Sept. 0·1 | 24 | Warm extreme, dry. |
| *Borneo*— | | | | | | | | | | | | | | | |
| Sandakan | 5° 50′ N. | 118° 7′ E. | 152 | 81 | 80 | 82 | 93 | 71 | 82 | 78 | 123·7 | Jan. 19·0 | April 4·5 | 177 | Hot, v. rainy. |
| *Burma*— | | | | | | | | | | | | | | | |
| Mandalay | 21°59′ N. | 96° 6′ E. | 252 | 80 | 69 | 85 | 107 | 48 | 65 | 72 | 32·6 | June 6·3 | Jan., Feb. 0·1 | 52 | Hot, mod. rainy. |
| Port Blair | 11°40′ N. | 92°43′ E. | 59 | 82 | 81 | 81 | 95 | 69 | 77 | 85 | 118·3 | June 19·6 | Mar. 0·8 | 139 | Hot, rainy summer. |
| Rangoon | 16°46′ N. | 96°11′ E. | 18 | 81 | 77 | 81 | 101 | 59 | 64 | 90 | 99·0 | July 21·4 | Jan., Feb. 0·2 | 123 | Hot, rainy summer. |
| *Celebes*— | | | | | | | | | | | | | | | |
| Menado | 1°30′ N. | 124°50′ E. | 5 | 78 | 77 | 79 | 94 | 67 | 91 | 79 | 104·4 | Jan. 18·3 | Sept. 3·4 | 164 | Hot rainy. |
| *Ceylon*— | | | | | | | | | | | | | | | |
| Colombo | 6°54′ N. | 79°52′ E. | 24 | 80 | 79 | 81 | 92 | 65 | 80 | 82 | 90·8 | May 15·0<br>Oct. 13·3 | Feb. 2·2<br>Aug. 2·6 | 190 | Hot rainy. |
| *China*— | | | | | | | | | | | | | | | |
| Canton | 23°11′ N. | 113°14′ E. | 100 | 73 | 59 | 84 | 97 | 40 | — | — | 63·6 | May 10·6 | Dec. 0·9 | 130 | Warm equable, rainy. |
| Chungking | 29°33′ N. | 106°33′ E. | 755 | 67 | 48 | 83 | 105 | 34 | 82 | 81 | 41·9 | June 6·7 | Jan. 0·7 | 133 | Warm, mod. rainy summer. |
| Hong Kong | 22°18′ N. | 114°10′ E. | 109 | 72 | 60 | 82 | 93 | 43 | 75 | 83 | 84·9 | June 15·5 | Dec. 1·1 | 141 | Warm equable, rainy. |
| Nanking | 32° 3′ N. | 118°47′ E. | 222 | 60 | 36 | 82 | — | — | 78 | 83 | 38·8 | July 7·3 | Dec. 1·4 | 127 | Warm extreme, mod. rainy. |
| Shanghai | 31°12′ N. | 121°26′ E. | 23 | 59 | 38 | 81 | 99 | 16 | 78 | 84 | 44·7 | June 7·1 | Dec. 1·4 | 130 | Warm extreme, rainy. |
| Tsientsin | 39°10′ N. | 117°10′ E. | 13 | 54 | 25 | 80 | 103 | 3 | 59 | 75 | 21·1 | July 7·4 | Feb. 0·1 | 63 | V. extreme, mod. rainy. |

# Climatic Tables—*continued*

| Place. | Lat. | Long. | Height. | Mean Temperature. Year. | Mean Temperature. Jan. | Mean Temperature. July. | Mean Annual. Max. | Mean Annual. Min. | Relative Humidity. Jan. | Relative Humidity. July. | Rainfall. Year. | Rainfall. Wettest Month. | Rainfall. Driest Month. | Days of Rain. | Climatic Character. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | feet. | ° F. | ° F. | ° F. | ° F. | ° F. | % | % | inches. | inches. | inches. | | |
| *Formosa—* | | | | | | | | | | | | | | | |
| Taihoku | 25° 2′ N. | 121°31′ E. | 30 | 71 | 59 | 83 | 97 | 41 | 84 | 78 | 83·8 | Aug. 12·0 | Nov. 2·6 | 185 | Warm equable, rainy. |
| *India and Pakhistan—* | | | | | | | | | | | | | | | |
| Allahabad | 25°26′ N. | 81°50′ E. | 309 | 77 | 59 | 85 | 114 | 40 | 63 | 78 | 38·3 | July 12·9 | Dec. April 0·2 | 45 | Warm equable, mod. rainy. |
| Bangalore | 12°57′ N. | 77°37′ E. | 3,021 | 74 | 69 | 74 | 99 | 53 | 58 | 74 | 36·1 | Sept. 7·3 | Jan. 0·2 | 58 | Hot, mod. rainy summer. |
| Bombay | 18°54′ N. | 72°49′ E. | 37 | 80 | 75 | 80 | 95 | 61 | 72 | 87 | 70·6 | July 24·3 | April 0·0 | 75 | Hot, rainy summer. |
| Calcutta | 22°32′ N. | 88°20′ E | 21 | 79 | 67 | 84 | 104 | 49 | 73 | 85 | 62·6 | Aug. 12·7 | Dec. 0·2 | 84 | Hot, rainy summer. |
| Delhi | 28°39′ N. | 77°17′ E. | 696 | 78 | 59 | 88 | 113 | 35 | 60 | 73 | 26·2 | July 7·6 | Nov. 0·1 | 35 | Warm dry. |
| Karachi | 24°48′ N. | 66°59′ E. | 13 | 77 | 67 | 83 | 103 | 47 | 56 | 82 | 7·5 | July 2·9 | Oct. 0·03 | 9 | Hot dry. |
| Lahore | 31°35′ N. | 74°20′ E. | 702 | 76 | 55 | 90 | 116 | 32 | 64 | 64 | 18·1 | July 5·1 | Nov. 0·1 | 27 | Warm dry. |
| Madras | 13° 4′ N. | 80°15′ E. | 22 | 83 | 76 | 87 | 107 | 62 | 76 | 70 | 50·7 | Nov. 14·3 | Mar. 0·2 | 57 | Hot, mod. rainy. |
| Peshawar | 34° 1′ N. | 71°34′ E. | 1,161 | 73 | 52 | 92 | 119 | 30 | 59 | 51 | 13·8 | Mar. 2·3 Aug. 2·1 | Nov. 0·2 June 0·3 | 24 | Warm dry. |
| Simla | 31° 6′ N. | 77°13′ E. | 7,283 | 56 | 40 | 65 | 80 | 26 | 53 | 86 | 63·1 | Aug. 17·4 | Nov. 0·5 | 84 | Equable, rainy summer. |
| *Indo-China—* | | | | | | | | | | | | | | | |
| Phu-Lien | 20°48′ N. | 106°38′ E. | 377 | 73 | 62 | 83 | 99 | 47 | 81 | 85 | 69·2 | Aug. 12·8 | Dec. Jan. 1·1 | 161 | Warm equable, rainy, foggy. |
| Saigon | 10°47′ N. | 106°42′ E. | 30 | 82 | 79 | 82 | 100 | 65 | 77 | 87 | 76·3 | Sept. 16·2 | Feb. 0·1 | 174 | Hot, rainy summer. |
| *Iran (Persia)—* | | | | | | | | | | | | | | | |
| Bushire | 29° 0′ N. | 50°50′ E. | 14 | 75 | 57 | 89 | 106 | 42 | 82 | 71 | 10·7 | Dec. 3·1 | June-Sept. 0·0 | 18 | Warm dry. |
| Teheran | 35°41′ N. | 51°25′ E. | 4,002 | 62 | 35 | 85 | 103 | 15 | 72 | 49 | 9·9 | Jan. 2·0 | Aug. 0·04 | 27 | V. extreme, dry. |
| *Iraq—* | | | | | | | | | | | | | | | |
| Baghdad | 33°21′ N. | 44°26′ E. | 120 | 71 | 49 | 92 | 118 | 29 | 78 | 37 | 6·6 | Dec. 1·2 Mar. 1·2 | June-Sept. 0·0 | 27 | Warm dry. |
| Basra (Shaibah) | 30°25′ N. | 47°39′ E. | 63 | 75 | 52 | 93 | 119 | 27 | 73 | 29 | 6·7 | Jan. 1·4 | June-Aug. 0·0 | 15 | Warm dry. |
| Mosul | 36°20′ N. | 43° 8′ E. | 698 | 66 | 43 | 90 | — | — | 83 | 31 | 13·0 | Feb. 3·0 | July-Sept. 0·0 | 61 | Warm dry, thundery. |
| *Japan—* | | | | | | | | | | | | | | | |
| Nagasaki | 32°44′ N. | 129°52′ E. | 436 | 60 | 42 | 77 | 93 | 25 | 70 | 82 | 75·0 | June 12·8 | Jan. 3·0 | 166 | Warm rainy. |
| Naha (Liu Kiu Is.) | 26°12′ N. | 127°39′ E. | 96 | 72 | 61 | 83 | 93 | 45 | 76 | 81 | 84·1 | June 10·4 | Dec. 4·1 | — | Hot rainy. |
| Nemuro | 43°20′ N. | 145°35′ E. | 89 | 42 | 23 | 57 | 82 | 1 | 72 | 92 | 37·9 | Sept. 5·5 | Feb. 1·1 | 156 | Cool extreme, rainy, v. foggy |
| Otomari (Saghalien) | 46°39′ N. | 142°46′ E. | 121 | 37 | 12 | 58 | 79 | −13 | 82 | 89 | 28·9 | Sept. 4·2 | Feb. 0·7 | 168 | V. extreme, rainy summer. |
| Tokyo | 35°41′ N. | 139°46′ E. | 19 | 57 | 37 | 75 | 93 | 21 | 63 | 82 | 61·4 | Sept. 8·9 | Dec. Jan. 2·2 | 149 | Warm extreme, rainy. |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Java*— | | | | | | | | | | | | | | | | |
| Batavia | 6°11′ S. | 106°50′ E. | 26 | 79 | 78 | 79 | 92 | 69 | 86 | 80 | 70·8 | Feb. 12·2 | Aug. 1·7 | 137 | Hot rainy, thundery. |
| *Korea*— | | | | | | | | | | | | | | | |
| Jinsen (Chemulpo) | 37°29′ N. | 126°38′ E. | 231 | 51 | 25 | 74 | 93 | 2 | 67 | 85 | 40·8 | July 10·9 | Feb. 0·7 | 105 | V. extreme, rainy summer. |
| *Malaya*— | | | | | | | | | | | | | | | |
| Singapore | 1°16′ N. | 103°49′ E. | 295 | 81 | 79 | 81 | 97 | 66 | 78 | 85 | 95·0 | Dec. 10·1 | July 6·7 | 179 | Hot rainy. |
| *Manchuria*— | | | | | | | | | | | | | | | |
| Mukden | 41°48′ N. | 123°23′ E. | 141 | 45 | 9 | 76 | 98 | −18 | 65 | 75 | 26·3 | July 6·4 | Jan. 0·2 | 93 | V. extreme, rainy summer. |
| *Mongolia*— | | | | | | | | | | | | | | | |
| Charbin | 45°43′ N. | 126°40′ E. | 526 | 38 | — | 72 | 92 | −31 | 72 | 70 | — | — | — | — | V. extreme, dry. |
| Urumtsi | 43°42′ N. | 87°36′ E. | 2,969 | 41 | 15 | 72 | — | — | — | — | 11·3 | Nov. 1·6 | Feb. 0·3 | 125 | V. extreme, mod. rainy. |
| *Palestine*— | | | | | | | | | | | | | | | |
| Haifa | 32°48′ N. | 34°59′ E. | 52 | 71 | 57 | 82 | 103 | 41 | 72 | 71 | 24·4 | Jan. 7·1 | June-Sept. 0·0 | 56 | Warm equable, rainless summer. |
| Jerusalem | 31°47′ N. | 35°13′ E. | 2,485 | 63 | 47 | 75 | 98 | 29 | 74 | 50 | 15·9 | Feb. 5·3 | June-Sept. 0·0 | 46 | Warm equable, dry. |
| *Philippines*— | | | | | | | | | | | | | | | |
| Manila | 14°35′ N. | 120°59′ E. | 47 | 80 | 76 | 80 | 98 | 62 | 77 | 85 | 96·3 | Aug. 24·0 | Mar. 0·5 | 159 | Hot, rainy summer. |
| Surigao | 9°48′ N. | 125°29′ E. | 20 | 80 | 78 | 81 | 94 | 69 | 88 | 79 | 157·3 | Dec. 28·7 | Aug. 5·5 | 225 | Hot, v. rainy. |
| *Siam*— | | | | | | | | | | | | | | | |
| Bangkok | 13°45′ N. | 100°30′ E. | 7 | 83 | 79 | 84 | 103 | 57 | 68 | 68 | 55·0 | Sept. 12·0 | Dec. 0·2 | 135 | Hot, mod. rainy. |
| *Sumatra*— | | | | | | | | | | | | | | | |
| Medan | 3°35′ N. | 98° 4′ E. | 77 | 78 | 77 | 79 | 95 | 66 | 85 | 81 | 79·9 | Oct. 10·2 | Feb. 3·6 | 142 | Hot, rainy. |
| Padang | 0°56′ S. | 100°22′ E. | 22 | 79 | 79 | 79 | 92 | 70 | 79 | 77 | 174·3 | Nov. 20·4 | Feb. 10·2 | 190 | Hot, v. rainy. |
| *Syria*— | | | | | | | | | | | | | | | |
| Beirut | 33°54′ N. | 35°28′ E. | 111 | 70 | 57 | 82 | 95 | 40 | 70 | 68 | 34·9 | Dec. 7·4 | July 0·0 | 78 | Warm equable, dry summer. |
| *Tibet*— | | | | | | | | | | | | | | | |
| Lhasa | 29°48′ N. | 91° 2′ E. | 12,238 | 48 | 32 | 61 | — | — | 22 | 57 | 63·0 | July 25·8 | Nov.-Jan. 0·0 | 90 | Cool, v. rainy, dry winter. |
| *Timor*— | | | | | | | | | | | | | | | |
| Koepang | 10°10′ S. | 123°34′ E. | 148 | 80 | 80 | 77 | 98 | 62 | 84 | 67 | 56·7 | Jan. 15·3 | Aug. Sept. 0·1 | 79 | Hot, mod. rainy. |
| *Transjordan*— | | | | | | | | | | | | | | | |
| Amman | 31°57′ N. | 35°37′ E. | 2,548 | 64 | 46 | 77 | 103 | 29 | 67 | 33 | 10·5 | Feb. 3·3 | June-Sept. 0·0 | 32 | Warm dry. |
| *Turkey*— | | | | | | | | | | | | | | | |
| Ankara | 39°58′ N. | 32°48′ E. | 2,910 | 53 | 32 | 72 | 98 | 6 | 77 | 41 | 11·7 | May 1·9<br>Dec. 1·7 | July 0·3 | 56 | Warm extreme, dry. |
| Smyrna | 38°26′ N. | 27° 9′ E. | 240 | 63 | 47 | 80 | 103 | 23 | 64 | 42 | 23·9 | Dec. 4·3 | July 0·2 | 69 | Warm, mod. rainy. |
| *U.S.S.R.*— | | | | | | | | | | | | | | | |
| Barnaoul | 53°20′ N. | 83°47′ E. | 531 | 33 | −2 | 67 | 91 | −44 | 81 | 65 | 13·8 | July 2·1 | Feb. 0·5 | 90 | V. extreme, mod. rainy, foggy. |
| Eneseisk | 58°27′ N. | 92°11′ E. | 277 | 29 | −9 | 66 | 89 | −54 | 82 | 73 | 16·8 | Aug. 2·6 | Mar. 0·5 | 146 | V. extreme, v. snowy. |
| Irkutsk | 52°16′ N. | 104°19′ E. | 1,532 | 30 | −6 | 64 | 89 | −44 | 82 | 72 | 14·9 | July 3·1 | Mar. 0·3 | 80 | V. extreme, foggy. |
| Markovo-on-Anadyr | 64°45′ N. | 170°50′ E. | 85 | 15 | −19 | 58 | 79 | −60 | 80 | 71 | 7·0 | Aug. 1·9 | April 0·1 | 102 | V. extreme, snowy. |
| Okhotsk | 59°21′ N. | 143°17′ E. | 18 | 22 | −11 | 53 | 73 | −36 | 69 | 87 | 11·8 | Aug. 2·6 | Dec.-Feb. 0·1 | 78 | V. extreme, snowy. |
| Sverdlovsk | 56°50′ N. | 60°38′ E. | 948 | 33 | 2 | 63 | — | — | 82 | 70 | 15·2 | July 2·9 | Feb. 0·3 | 108 | V. extreme, mod. rainy. |
| Tashkent | 41°20′ N. | 69°18′ E. | 1,569 | 56 | 30 | 80 | 102 | −5 | 72 | 42 | 14·1 | Mar. 2·6 | Aug. 0·0 | 59 | V. extreme, mod. rainy. |
| Verkhoyansk | 67°33′ N. | 133°24′ E. | 328 | 3 | −59 | 60 | 85 | −82 | 70 | 58 | 5·1 | July 1·1 | Mar. 0·1 | 34 | V. extreme, dry. |
| Vladivostok | 43° 7′ N. | 131°54′ E. | 420 | 40 | 6 | 65 | 87 | −15 | 67 | 89 | 23·6 | Aug. 4·7 | Jan. 0·3 | 91 | V. extreme, rainy summer, v. foggy. |

# Climatic Tables—*continued*

| Place. | Lat. | Long. | Height. | Mean Temperature. | | | Mean Annual. | | Relative Humidity. | | Rainfall. | | | Days of Rain. | Climatic Character. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Year. | Jan. | July. | Max. | Min. | Jan. | July. | Year. | Wettest Month. | Driest Month. | | |
| NORTH AMERICA. | | | | | | | | | | | | | | | |
| *Alaska*— | | | feet. | ° F. | ° F. | ° F. | ° F. | ° F. | % | % | inches. | inches. | inches. | | |
| Dutch Harbour | 53°55′ N. | 166°30′ W. | 50 | 40 | 31 | 51 | 72 | 10 | — | 81 | 111·1 | Jan. 17·9 | July 3·0 | 253 | Cool equable, v. rainy, foggy. |
| Nome | 64°30′ N. | 165°24′ W. | 22 | 25 | 2 | 50 | 73 | −36 | — | — | 17·2 | Aug. 3·2 | April 0·5 | 106 | Cool extreme, snowy. |
| Sitka | 57° 3′ N. | 135°19′ W. | 65 | 44 | 32 | 53 | 77 | 7 | — | — | 83·6 | Oct. 12·0 | June 3·1 | 213 | Cool equable, v. rainy. |
| *Canada*— | | | | | | | | | | | | | | | |
| Charlottetown, P.E.I. | 46°15′ N. | 63° 7′ W. | 74 | 42 | 18 | 65 | 85 | −14 | 78 | 79 | 39·5 | Oct. 4·1 | June 2·6 | 140 | Extreme, v. rainy. |
| Chesterfield | 63°45′ N. | 91°15′ W. | 13 | 11 | −26 | 48 | — | — | — | 83 | 12·3 | July 2·2 | Jan. Mar. 0·2 | 55 | V. extreme, mod. rainy summer. |
| Dawson | 64° 4′ N. | 139°29′ W. | 1,063 | 23 | −22 | 59 | 87 | −54 | — | 75 | 12·4 | July Aug. 1·5 | Mar. 0·5 | 92 | V. extreme, mod. rainy summer. |
| Edmonton | 53°33′ N. | 113°30′ W. | 2,146 | 37 | 5 | 61 | 89 | −34 | 81 | 68 | 17·3 | July 3·4 | Feb. 0·6 | 111 | V. extreme, mod. rainy. |
| Halifax N.S. | 44°39′ N. | 63°36′ W. | 88 | 44 | 27 | 65 | 89 | −8 | 88 | 86 | 57·1 | Nov. 5·9 | July 3·6 | 167 | Cool extreme, mod. rainy. |
| Hebron, Labrador | 58°12′ N. | 62°21′ W. | 49 | 23 | −6 | 47 | 79 | −32 | 82 | 85 | 19·4 | Sept. 3·3 | Dec. 0·6 | 125 | V. extreme, cold, snowy. |
| Montreal | 45°30′ N. | 73°34′ W. | 187 | 43 | 13 | 69 | 90 | −19 | 76 | 73 | 40·8 | Jan. 3·8 | April 2·6 | 157 | V. extreme, v. rainy. |
| Ottawa | 45°26′ N. | 75°42′ W. | 236 | 42 | 12 | 69 | — | — | 81 | 74 | 34·2 | Oct. 3·4 | April 2·3 | 153 | V. extreme, rainy. |
| Quebec | 46°48′ N. | 71°13′ W. | 296 | 39 | 10 | 67 | 89 | −23 | 79 | 75 | 39·7 | July Aug. 4·0 | April 2·3 | 163 | V. extreme, rainy. |
| St. John N.B. | 45°17′ N. | 66° 4′ W. | 119 | 42 | 19 | 61 | 83 | −14 | 76 | 83 | 46·1 | Nov. 4·5 | June 3·2 | 153 | Cool extreme, v. rainy, foggy. |
| St. John's, Newf'ndland | 47°34′ N. | 52°42′ W. | 243 | 41 | 24 | 59 | 83 | −6 | 76 | 79 | 53·9 | Nov. 5·9 | June 3·5 | 178 | Cool extreme, v. rainy. |
| Toronto | 43°40′ N. | 79°24′ W. | 381 | 45 | 22 | 69 | 96 | −11 | 82 | 72 | 32·3 | Sept. 3·0 | April 2·4 | 147 | Extreme, rainy. |
| Victoria, B.C. | 48°24′ N. | 123°19′ W. | 228 | 50 | 39 | 60 | 86 | 19 | 86 | 73 | 27·0 | Dec. 4·7 | July 0·4 | 150 | Cool equable, v. rainy winter. |
| Winnipeg | 49°53′ N. | 97° 7′ W. | 758 | 35 | −3 | 67 | 95 | −30 | 86 | 68 | 20·6 | June 3·1 | Jan. 0·9 | 106 | V. extreme, rainy summer. |
| *Mexico*— | | | | | | | | | | | | | | | |
| Mazatlan | 23°15′ N. | 106°30′ W. | 249 | 74 | 67 | 81 | 92 | 53 | 76 | 78 | 31·2 | Sept. 10·3 | April May 0·0 | 66 | Hot, mod. rain. |
| Mexico City | 19°26′ N. | 99° 8′ W. | 7,472 | 60 | 54 | 62 | 85 | 33 | 56 | 68 | 22·8 | July 4·5 | Jan. 0·2 | 148 | Warm equable, mod. rain. |
| Salina Cruz | 16°10′ N. | 95°12′ W. | 184 | 80 | 76 | 82 | 96 | 63 | 57 | 68 | 40·3 | June 14·6 Sept. 10·2 | Feb. Mar. 0·0 | 61 | Hot, mod. rain, dry winter. |
| Vera Cruz | 19°12′ N. | 96°10′ W. | 48 | 77 | 70 | 81 | — | — | 81 | 81 | 61·4 | July 13·0 | Mar. 0·5 | 133 | Hot, rainy summer. |
| *United States*— | | | | | | | | | | | | | | | |
| Boston, Mass. | 42°21′ N. | 71° 4′ W. | 125 | 50 | 28 | 72 | — | — | 72 | 71 | 40·1 | Jan. Aug. 3·6 | June 2·9 | 125 | Warm extreme, rainy. |
| Charleston | 32°47′ N. | 79°56′ W. | 48 | 66 | 50 | 81 | 98 | 24 | 74 | 75 | 45·1 | July 6·9 | Nov. 2·1 | 114 | Warm, rainy. |
| Chicago | 41°53′ N. | 87°37′ W. | 823 | 49 | 24 | 72 | 98 | −7 | — | — | 33·5 | May 3·5 | Dec. 2·1 | 125 | Extreme, rainy. |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Denver | 39°45′ N. | 105° 0′ W. | 5,279 | 50 | 29 | 72 | 96 | −11 | 55 | 51 | 14·1 | May 2·2 | Jan. 0·4 | 84 | Warm extreme, dry. |
| Galveston | 29°18′ N. | 94°50′ W. | 9 | 70 | 54 | 83 | 94 | 26 | 85 | 77 | 45·3 | Sept. 5·6 | Mar. 2·7 | 99 | Warm equable, mod. rainy. |
| Key West | 24°33′ N. | 81°48′ W. | 22 | 77 | 69 | 83 | 91 | 52 | 80 | 72 | 38·1 | Sept. 6·7 | Feb. 1·3 | 112 | Hot, mod. rainy. |
| Los Angeles | 34° 3′ N. | 118°17′ W. | 361 | 62 | 54 | 70 | — | — | 65 | 75 | 15·2 | Feb. 3·3 | July, Aug. 0·0 | 38 | Warm equable, dry. |
| Miami | 25°46′ N. | 80°12′ W. | 83 | 75 | 67 | 82 | — | — | 79 | 75 | 55·7 | Sept. 8·5 | Dec. 1·7 | 117 | Hot rainy. |
| New Orleans | 29°57′ N. | 90° 4′ W. | 30 | 70 | 55 | 82 | 97 | 26 | 79 | 78 | 59·3 | July 6·5 | Nov. 3·5 | 120 | Warm equable, rainy, v. thundery. |
| New York | 40°43′ N. | 74° 0′ W. | 314 | 52 | 31 | 74 | 96 | 1 | 74 | 72 | 42·8 | Aug. 4·3 | Nov. 3·0 | 125 | Warm extreme, rainy. |
| Philadelphia | 39°57′ N. | 75° 9′ W. | 114 | 54 | 33 | 76 | — | — | 70 | 66 | 40·4 | Aug. 4·6 | Nov. 2·7 | 124 | Warm extreme, rainy. |
| Portland Or. | 45°32′ N. | 122°41′ W. | 153 | 53 | 39 | 67 | 96 | 20 | 81 | 60 | 41·6 | Dec. 6·7 | July, Aug. 0·6 | 154 | Warm rainy, dry summer. |
| St. Louis | 38°38′ N. | 90°12′ W. | 568 | 56 | 31 | 78 | 99 | −3 | 75 | 67 | 37·4 | May 4·2 | Dec. 2·2 | 110 | Warm extreme, rainy. |
| Salt Lake City | 40°46′ N. | 111°54′ W. | 4.347 | 52 | 29 | 77 | 98 | 5 | 73 | 35 | 16·1 | April 2·1 | July 0·5 | 90 | Warm extreme, mod. rainy. |
| San Francisco | 37°48′ N. | 122°26′ W. | 155 | 56 | 50 | 58 | 91 | 37 | 76 | 78 | 21·9 | Jan. 4·5 | July, Aug. 0·0 | 66 | Warm equable, mod. rainy. |
| Seattle | 47°36′ N. | 122°20′ W. | 125 | 51 | 40 | 63 | — | — | 82 | 66 | 34·0 | Dec. 5·6 | July 0·6 | 151 | Warm equable, rainy, dry summer. |
| Washington, D.C. | 38°54′ N. | 77° 3′ W. | 112 | 55 | 33 | 77 | 98 | 6 | 65 | 66 | 42·2 | July 4·7 | Nov. 2·4 | 126 | Warm extreme, rainy. |
| Yuma | 32°45′ N. | 114°36′ W. | 141 | 72 | 54 | 91 | — | — | 46 | 45 | 3·3 | Jan. 0·5, Aug. 0·6 | May, June 0·0 | 15 | Warm, v. dry. |
| CENTRAL AMERICA. | | | | | | | | | | | | | | | |
| *British Honduras*— | | | | | | | | | | | | | | | |
| Belize | 17°31′ N. | 88°11′ W. | 17 | 79 | 75 | 81 | 91 | 56 | 83 | 77 | 75·8 | Oct. 13·5 | Mar. 1·6 | 150 | Hot rainy. |
| *Costa Rica*— | | | | | | | | | | | | | | | |
| San José | 9°56′ N. | 84° 5′ W. | 3,730 | 67 | 66 | 68 | — | — | 76 | 83 | 70·8 | Sept. 12·0 | Feb. 0·2 | 170 | Hot rainy, dry winter. |
| *Guatemala*— | | | | | | | | | | | | | | | |
| Guatemala | 14°37′ N. | 90°31′ W. | 4,856 | 68 | 63 | 69 | — | — | 72 | 82 | 51·8 | June 10·8 | Feb. 0·1 | 145 | Warm equable, rainy, dry winter. |
| *Panama*— | | | | | | | | | | | | | | | |
| Balbao Heights | 9° 0′ N. | 79°35′ W. | 118 | 79 | 78 | 79 | 94 | 67 | 78 | 87 | 69·7 | Nov. 10·6 | Mar. 0·7 | 174 | Hot, rainy summer and autumn. |
| Cristobal (Colon) | 9°21′ N. | 79°54′ W. | 36 | 80 | 80 | 80 | 91 | 71 | 79 | 86 | 129·9 | Nov. 22·4 | Feb. 1·5 | 241 | Hot, v. rainy summer and autumn. |
| *San Salvador*— | | | | | | | | | | | | | | | |
| San Salvador | 13°42′ N. | 89°13′ W. | 2,238 | 74 | 72 | 75 | 100 | 51 | 69 | 80 | 68·3 | July 12·1 | Jan. 0·2 | 142 | Hot, rainy summer. |
| WEST INDIES. | | | | | | | | | | | | | | | |
| *Bahamas*— | | | | | | | | | | | | | | | |
| Nassau | 25°51′ N. | 77°21′ W. | 12 | 77 | 71 | 82 | 92 | 55 | 74 | 69 | 50·3 | Sept. 7·4 | Dec. 1·5 | 132 | Hot, mod. rainy. |
| *Barbados* | 13° 8′ N. | 59°36′ W. | 181 | 78 | 74 | 80 | 89 | 65 | 64 | 69 | 53·7 | Sept. 7·6 | April 1·6 | 178 | Hot, mod. rainy. |
| *Bermuda* | 32°17′ N. | 64°46′ W. | 151 | 71 | 63 | 80 | 91 | 46 | 78 | 77 | 57·6 | Oct. 5·8 | April 4·1 | 162 | Warm, equable, rainy. |
| *Cuba*— | | | | | | | | | | | | | | | |
| Havana | 23° 8′ N. | 82°21′ W. | 80 | 76 | 70 | 80 | 93 | 53 | 74 | 74 | 48·1 | Oct. 6·8 | Mar. 1·8 | 121 | Hot, mod. rainy. |
| *Haiti*— | | | | | | | | | | | | | | | |
| Port au Prince | 18°34′ N. | 72°22′ W. | 123 | 79 | 76 | 82 | 99 | 63 | 63 | 64 | 54·1 | May 9·4 | Jan. 1·2 | 127 | Hot, mod. rainy. |

## CLIMATIC TABLES—*continued*

| Place. | Lat. | Long. | Height. | Mean Temperature. Year. | Mean Temperature. Jan. | Mean Temperature. July. | Mean Annual. Max. | Mean Annual. Min. | Relative Humidity. Jan. | Relative Humidity. July. | Rainfall. Year. | Rainfall. Wettest Month. | Rainfall. Driest Month. | Days of Rain. | Climatic Character. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | feet. | ° F. | ° F | ° F. | °F. | ° F. | % | % | inches. | inches. | inches. | | |
| *Jamaica*— | | | | | | | | | | | | | | | |
| Kingston | 17°58′ N. | 76°48′ W. | 110 | 79 | 76 | 81 | 94 | 62 | 78 | 76 | 31·5 | Oct. 7·1 | Feb. 0·6 | 79 | Hot, mod. rainy. |
| *Martinique*— | | | | | | | | | | | | | | | |
| Fort-de-France | 14°36′ N. | 61° 6′ W. | 13 | 79 | 76 | 80 | 92 | 62 | 82 | 83 | 86·8 | Nov. 11·1 | April 2·8 | 230 | Hot rainy. |
| *Porto Rico*— | | | | | | | | | | | | | | | |
| San Juan | 18°29′ N. | 66° 7′ W. | 82 | 78 | 75 | 80 | 92 | 65 | 77 | 77 | 64·5 | Aug. 7·4 | Feb. 2·5 | 214 | Hot rainy. |
| *Trinidad*— | | | | | | | | | | | | | | | |
| Port of Spain | 10°40′ N. | 61°31′ W. | 72 | 77 | 75 | 78 | 95 | 61 | 80 | 80 | 63·5 | Aug. 9·6 | Feb. 1·5 | 174 | Hot rainy. |
| SOUTH AMERICA. | | | | | | | | | | | | | | | |
| *Argentine*— | | | | | | | | | | | | | | | |
| Buenos Aires | 34°35′ S. | 58°29′ W. | 89 | 61 | 74 | 49 | 99 | 27 | 69 | 84 | 37·4 | Mar. 4·3 | July 2·2 | 82 | Warm equable, rainy, foggy. |
| Cordoba | 31°25′ S. | 64°12′ W. | 1,388 | 62 | 74 | 50 | 105 | 20 | 63 | 63 | 27·7 | Dec. 4·6 | June, July 0·3 | 75 | Warm equable, mod. rainy. |
| *Bolivia*— | | | | | | | | | | | | | | | |
| La Paz | 16°30′ S. | 68° 9′ W. | 12,001 | 49 | 51 | 44 | — | — | 65 | 39 | 22·2 | Jan. 4·5 | June 0·2 | 126 | Warm equable, mod. rainy. |
| Sucre | 19° 3′ S. | 65°17′ W. | 9,344 | 54 | 55 | 49 | — | — | 70 | 50 | 27·2 | Jan. 6·5 | July 0·2 | — | Warm equable, mod. rainy. |
| *Brazil*— | | | | | | | | | | | | | | | |
| Manaos | 3° 8′ S. | 60° 1′ W. | 144 | 81 | 80 | 81 | 98 | 70 | 81 | 77 | 71·1 | Mar. 10·3 | Aug. 1·5 | 153 | Hot rainy. |
| Para | 1°27′ S. | 48°29′ W. | 42 | 78 | 78 | 78 | 93 | 67 | 92 | 89 | 96·0 | Feb. 14·1 | Nov. 2·6 | 251 | Hot rainy. |
| Pernambuco (Recife) | 8° 4′ S. | 34°53′ W. | 97 | 80 | 82 | 77 | 90 | 67 | 72 | 77 | 65·7 | June 11·6 | Nov. 0·9 | 165 | Hot, rainy winter, foggy. |
| Rio de Janeiro | 22°54′ S. | 43°10′ W. | 201 | 73 | 78 | 68 | 96 | 56 | 78 | 78 | 43·6 | Dec., Mar. 5·5 | July 1·7 | 125 | Hot, mod. rainy. |
| *British Guiana*— | | | | | | | | | | | | | | | |
| Georgetown | 6°50′ N. | 58°12′ W. | 6 | 80 | 79 | 80 | 90 | 70 | 81 | 82 | 88·7 | June 11·9<br>Dec. 11·3 | Oct. 3·0 | 207 | Hot rainy. |
| *Chile*— | | | | | | | | | | | | | | | |
| Antofagasta | 23°42′ S. | 70°24′ W. | 308 | 63 | 70 | 57 | 81 | 47 | 71 | 72 | 0·5 | July 0·2 | — | 2 | Warm equable, nearly rainless. |
| Arica | 18°28′ S. | 70°20′ W. | 95 | 65 | 70 | 60 | 80 | 50 | 73 | 74 | 0·0 | — | — | 0 | Warm equable, rainless. |
| Punta Arenas | 53°10′ S. | 70°54′ W. | 92 | 44 | 52 | 35 | 72 | 22 | 63 | 79 | 15·2 | Mar., May 1·7 | Oct. 0·7 | 116 | Cool equable, mod. rainy. |
| Santiago | 33°27′ S. | 70°42′ W. | 1,706 | 59 | 69 | 48 | 92 | 27 | 61 | 83 | 14·1 | June 3·3 | Feb. 0·1 | 49 | Warm equable, dry. |
| Valdivia | 39°48′ S. | 73°14′ W. | 16 | 54 | 62 | 47 | 89 | 28 | 71 | 90 | 103·5 | June 18·1 | Jan. 2·7 | 163 | Warm equable, v. rainy. |
| Valparaiso | 33° 1′ S. | 71°38′ W. | 135 | 59 | 64 | 53 | 86 | 39 | 75 | 80 | 19·9 | June 5·9 | Feb. 0·0 | 41 | Warm equable, mod. rainy, foggy. |
| *Columbia*— | | | | | | | | | | | | | | | |
| Bogota | 4°36′ N. | 74° 5′ W. | 8,678 | 58 | 58 | 57 | 74 | 42 | 71 | 72 | 39·5 | April 5·3<br>Oct. 5·5 | July 1·8<br>Jan. 2·2 | 177 | Warm equable, rainy. |
| *Ecuador*— | | | | | | | | | | | | | | | |
| Guyaquil | 2°12′ S. | 79°51′ W. | 40 | 78 | 80 | 76 | 88 | 68 | 80 | 79 | 40·2 | Jan. 10·7 | Aug. 0·0 | 66 | Hot, mod. rainy. |
| Quito | 0°14′ S. | 78°32′ W. | 9,350 | 57 | 57 | 57 | — | — | 76 | 61 | 43·1 | April 7·2 | July 0·8 | 171 | Warm, equable rainy. |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Paraguay*— Asuncion | 25°17′ S. | 57°30′ W. | 456 | 72 | 81 | 64 | 105 | 35 | 72 | 74 | 51·8 | Dec. 6·2 | Aug. 1·5 | 78 | Warm equable, rainy. |
| *Peru*— Lima | 12° 5′ S. | 77° 3′ W. | 364 | 65 | 71 | 60 | 88 | 51 | 85 | 88 | 1·5 | Aug. 0·3 | — | 43 | Warm equable, nearly rainless. |
| *Uruguay*— Montevideo | 34°52′ S. | 56°12′ W. | 72 | 63 | 73 | 52 | 92 | 36 | 68 | 81 | 39·3 | April 4·3 | Oct. 2·5 | 87 | Warm equable, rainy. |
| *Venezuela*— Caracas | 10°30′ N. | 66°56′ W. | 3,418 | 67 | 65 | 68 | 87 | 49 | 78 | 80 | 31·8 | July 4·3 | Feb. 0·4 | — | Hot, mod. rainy. |
| *Falkland Islands*— Stanley | 51°42′ S. | 57°51′ W. | 6 | 42 | 49 | 36 | 69 | 18 | 77 | 90 | 25·7 | Dec. 2·8 | Sept. 1·4 | 222 | Cool equable, rainy. |
| AFRICA. | | | | | | | | | | | | | | | |
| *Abyssinia*— Addis Ababa | 9° 2′ N | 38°45′ E. | 8,038 | 59 | 58 | 58 | — | — | 52 | 86 | 48·7 | Aug. 11·8 | Dec. 0·2 | 138 | Warm equable, rainy summer, foggy, v. thundery. |
| *Algeria*— Algiers | 36°46′ N. | 3° 3′ E. | 194 | 64 | 53 | 75 | 101 | 38 | 65 | 68 | 29·8 | Dec. 5·1 | July 0·1 | 113 | Warm equable, mod. rainy. |
| Insalah | 27° 6′ N. | 2°30′ E. | 1,083 | 78 | 55 | 99 | — | — | 49 | 21 | 0·3 | Very irregular. | | 5 | Warm nearly rainless. |
| Oran | 35°42′ N. | 0°39′ W. | 171 | 63 | 53 | 73 | 98 | 36 | 77 | 74 | 14·8 | Jan. 2·8 | July 0·0 | 64 | Warm equable, dry. |
| *Angola*— Luanda | 8°49′ S. | 13°13′ E. | 150 | 75 | 78 | 69 | 91 | 60 | 80 | 83 | 13·1 | April 4·7 | June-Aug. 0·0 | 81 | Hot dry. |
| Mossamedes | 15°12′ S. | 12° 9′ E. | 41 | 68 | 71 | 61 | — | — | 81 | 83 | 3·9 | April 1·6 | May-Oct. 0·0 | 69 | Warm equable, dry. |
| *Belgian Congo*— Eala | 0° 3′ S. | 18°15′ E. | 1,083 | 77 | 78 | 76 | 96 | 60 | 76 | 77 | 70·8 | Oct. 8·9 | July 3·0, Jan. 3·4 | 146 | Hot rainy. |
| Leopoldville | 4°20′ S. | 15°18′ E. | 1,066 | 77 | 77 | 73 | — | — | 82 | 84 | 56·5 | Mar., Nov. 8·9 | June 0·0 | 111 | Hot, mod. rainy. |
| Elizabethville | 11°38′ S. | 27°31′ E. | 4,170 | 69 | 71 | 61 | 97 | 37 | 82 | 84 | 45·3 | Dec. 10·1 | June-Aug. 0·0 | 131 | Warm equable, mod. rainy. |
| *British Somaliland*— Berbera | 10°22′ N. | 45° 2′ E. | 45 | 86 | 77 | 97 | 112 | 62 | 73 | 47 | 2·5 | Mar. 0·6 | June 0·0 | 8 | Hot dry. |
| *Cameroons*— Duala | 4° 3′ N. | 9°41′ E. | 26 | 78 | 80 | 75 | 91 | 68 | 85 | 91 | 158·5 | July 29·2 | Jan. 1·8 | 212 | Hot, v. rainy summer. |
| *Egypt*— Alexandria | 31°12′ N. | 29°53′ E. | 103 | 68 | 56 | 77 | 103 | 42 | 67 | 76 | 7·2 | Dec. 2·3 | May-Sept. 0·0 | 41 | Warm equable, dry. |
| Cairo (Helwan) | 29°52′ N. | 31°20′ E. | 379 | 69 | 54 | 81 | 108 | 39 | 59 | 47 | 1·2 | Jan. 0·3 | May-Oct. 0·0 | 11 | Warm equable, nearly rainless. |
| *Eritrea*— Massawa | 15°37′ N. | 39°27′ E. | 64 | 86 | 79 | 95 | 109 | 67 | 73 | 56 | 7·3 | Dec., Jan. 1·7 | June 0·0 | 32 | Hot dry. |
| *French Equatorial Africa*— Libreville | 0°23′ N. | 9°26′ E. | 115 | 79 | 80 | 76 | 94 | 65 | 85 | 83 | 97·2 | Nov. 14·6 | July 0·0 | 136 | Hot rainy (dry June–August). |
| *French West Africa*— Dakar | 14°40′ N. | 17°26′ W. | 105 | 77 | 71 | 82 | — | — | 56 | 73 | 21·3 | Aug. 9·6 | Jan.-May 0·0 | 45 | Hot dry. |
| Niamey | 13°31′ N. | 2° 6′ E. | 709 | 84 | 74 | 84 | — | — | 25 | 63 | 24·4 | Aug. 9·6 | Dec.-Mar. 0·0 | 47 | Hot dry. |
| Timbuktu | 16°43′ N. | 3° 1′ W. | 935 | 83 | 66 | 89 | 116 | 41 | 34 | 57 | 9·0 | Aug. 3·9 | Nov.-Mar. 0·0 | 26 | Hot dry. |

## Climatic Tables—*continued*

| Place. | Lat. | Long. | Height. | Mean Temperature. | | | Mean Annual. | | Relative Humidity. | | Rainfall. | | | Days of Rain. | Climatic Character. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Year. | Jan. | July. | Max. | Min. | Jan. | July. | Year. | Wettest Month. | Driest Month. | | |
| | | | feet. | ° F. | ° F. | ° F. | ° F. | ° F. | % | % | inches. | inches. | inches. | | |
| *Gambia*— | | | | | | | | | | | | | | | |
| Bathurst | 13°24′ N. | 16°36′ W. | 22 | 78 | 74 | 80 | 101 | 57 | 57 | 79 | 47·7 | Aug. 19·6 | Jan.-April 0·0 | 63 | Hot, mod. rain. |
| *Gold Coast*— | | | | | | | | | | | | | | | |
| Accra | 5°33′ N. | 0°12′ W. | 88 | 79 | 81 | 77 | 93 | 62 | 76 | 85 | 27·6 | June 7·0 | Jan. Aug. 0·6 | 54 | Hot dry. |
| *Kamaran Is.* (Red Sea) | 15°20′ N. | 42°36′ E. | 25 | 85 | 78 | 92 | 103 | 69 | 73 | 54 | 3·1 | Dec. 0·7 | April-Oct. 0·0 | 12 | Hot dry. |
| *Kenya*— | | | | | | | | | | | | | | | |
| Mombasa | 4° 4′ S. | 39°42′ E. | 52 | 81 | 82 | 77 | 94 | 68 | 72 | 77 | 47·3 | May 12·5 | Feb. 0·7 | 155 | Hot, mod. rainy. |
| Nairobi | 1°14′ S. | 36°44′ E. | 5,900 | 64 | 64 | 60 | 85 | 40 | 61 | 72 | 40·3 | April 9·8 | July 0·8 | 127 | Warm equable, mod. rainy. |
| *Libya*— | | | | | | | | | | | | | | | |
| Benghazi | 32° 7′ N. | 20° 2′ E. | 261 | 68 | 57 | 77 | 100 | 46 | 67 | 67 | 10·5 | Jan. 2·6 | June-Aug. 0·0 | 56 | Warm equable, dry. |
| Tripoli | 32°54′ N. | 13°11′ E. | 72 | 67 | 54 | 78 | 105 | 39 | 65 | 66 | 15·1 | Dec. 3·7 | July Aug. 0·0 | 54 | Warm equable, dry. |
| *Madagascar*— | | | | | | | | | | | | | | | |
| Tamatave | 18° 7′ S. | 49°24′ E. | 20 | 75 | 81 | 70 | 97 | 59 | 84 | 84 | 118·6 | Mar. 15·9 | Oct. 4·0 | 180 | Hot, v. rainy. |
| Tananarive | 18°55′ S. | 47°33′ E. | 4,500 | 65 | 70 | 58 | 88 | 41 | 79 | 76 | 51·4 | Jan. 11·5 | July 0·2 | 92 | Warm equable, rainy summer. |
| *Morocco*— | | | | | | | | | | | | | | | |
| Cape Spartel | 35°47′ N. | 5°55′ W. | 197 | 63 | 55 | 73 | 96 | 40 | 80 | 73 | 30·4 | Nov. 5·5 | July Aug. 0·1 | 85 | Warm equable, mod. rainy. |
| *Mozambique*— | | | | | | | | | | | | | | | |
| Beira | 19°50′ S. | 34°51′ E. | 23 | 76 | 81 | 68 | 101 | 53 | 75 | 79 | 58·2 | Jan. 11·7 | Sept. 0·8 | 111 | Hot, rainy summer. |
| Lourenco Marques | 25°58′ S. | 32°36′ E. | 194 | 72 | 77 | 65 | 105 | 48 | 76 | 73 | 29·6 | Feb. 5·4 | Aug. 0·4 | 95 | Warm equable, mod. rainy. |
| *Nigeria*— | | | | | | | | | | | | | | | |
| Kaduna | 10°32′ N. | 7°25′ E. | 1,915 | 77 | 73 | 76 | 101 | 51 | 34 | 85 | 55·0 | Aug. 12·8 | Jan. 0·0 | 116 | Hot, mod. rainy. |
| Lagos | 6°27′ N. | 3°24′ E. | 22 | 81 | 81 | 78 | 95 | 67 | 74 | 82 | 72·3 | June 18·1 | Dec. 1·0 | 124 | Hot rainy. |
| *Nyasaland*— | | | | | | | | | | | | | | | |
| Zomba | 15°23′ S. | 35°18′ E. | 3,100 | 67 | 70 | 59 | 95 | 45 | 85 | 75 | 54·5 | Jan. 11·1 | July 0·3 | 118 | Warm equable, rainy summer. |
| *Rhodesia*— | | | | | | | | | | | | | | | |
| Salisbury | 17°48′ S. | 31° 5′ E. | 4,885 | 66 | 70 | 56 | 91 | 35 | 74 | 57 | 32·0 | Jan. 7·4 | June July 0·0 | 86 | Warm equable, mod. rainy. |
| *Sierra Leone*— | | | | | | | | | | | | | | | |
| Freetown | 8°29′ N. | 13°14′ W. | 180 | 81 | 81 | 79 | 96 | 66 | 73 | 84 | 142·7 | July 35·5 | Feb. 0·2 | 173 | Hot, v. rainy summer. |
| *Somaliland*— | | | | | | | | | | | | | | | |
| Jibouti | 11°35′ N. | 43° 9′ E. | 20 | 86 | 78 | 96 | 113 | 67 | — | — | 5·1 | Mar. 0·8 | June 0·0 | 16 | Hot dry. |
| Mogadiscio | 2° 1′ N. | 45°20′ E. | 39 | 81 | 81 | 79 | — | — | 87 | 92 | 19·0 | June 3·7 | Jan.-Mar. 0·0 | 55 | Hot dry. |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *South-West Africa—* | | | | | | | | | | | | | | | |
| Walvis Bay | 22°56′ S. | 14°30′ E. | 24 | 62 | 66 | 57 | 98 | 35 | 85 | 77 | 0·3 | — | — | 8 | Warm equable, nearly rainless, foggy. |
| Windhuk | 22°34′ S. | 17° 6′ E. | 5,463 | 66 | 74 | 55 | 94 | 29 | 41 | 35 | 14·0 | Jan. 5·4 | May 0·0 | 54 | Warm equable, dry, thundery. |
| *Soudan—* | | | | | | | | | | | | | | | |
| Khartoum | 15°37′ N. | 32°33′ E. | 1,280 | 83 | 70 | 89 | 114 | 49 | 26 | 43 | 5·2 | Aug. 2·2 | Nov.-April 0·0 | 15 | Hot dry. |
| Mongalla | 5°11′ N. | 31°47′ E. | 1,440 | 79 | 81 | 76 | 107 | — | 48 | 84 | 38·5 | Aug. 5·6 | Jan. 0·1 | 94 | Hot, mod. rainy. |
| *Tanganyika—* | | | | | | | | | | | | | | | |
| Dar-es-salaam | 6°50′ S. | 39°17′ E. | 30 | 79 | 83 | 76 | 93 | 63 | 80 | 81 | 41·0 | April 11·1 | Aug. 1·0 | 106 | Hot, mod. rainy. |
| *Tunisia—* | | | | | | | | | | | | | | | |
| Tunis | 36°48′ N. | 10°10′ E. | 108 | 64 | 51 | 79 | 110 | 34 | 76 | 55 | 16·6 | Dec. 2·4 | July 0·1 | 79 | Warm equable, dry. |
| *Uganda—* | | | | | | | | | | | | | | | |
| Entebbe | 0° 5′ N. | 32°29′ E. | 3,842 | 70 | 71 | 69 | 87 | 56 | 78 | 79 | 58·0 | April 9·8 | Jan. 2·6 July 3·0 | 136 | Hot rainy. |
| *Union of South Africa—* | | | | | | | | | | | | | | | |
| Cape Town | 33°56′ S. | 18°29′ E. | 40 | 63 | 71 | 55 | 99 | 36 | 57 | 77 | 24·7 | June 4·3 | Feb. 0·6 | 97 | Warm equable, mod. rainy. |
| Durban | 29°52′ S. | 31° 3′ E. | 50 | 70 | 76 | 63 | 92 | 45 | 73 | 65 | 45·1 | Mar. 6·0 | July 1·7 | 115 | Warm equable, mod. rainy. |
| East London | 33° 1′ S. | 27°54′ E. | 149 | 65 | 70 | 59 | 92 | 40 | 76 | 75 | 32·5 | Mar. 3·8 | June 1·5 | 102 | Warm equable, mod. rainy. |
| Johannesburg | 26°11′ S. | 28° 4′ E. | 5,925 | 60 | 67 | 50 | 89 | 27 | 73 | 48 | 33·2 | Jan. 6·2 | June 0·2 | 97 | Warm equable, mod. rainy summer. |
| Kimberley | 28°43′ S. | 24°46′ E. | 4,000 | 63 | 75 | 49 | 101 | 23 | 52 | 60 | 17·6 | Feb. 3·1 | Aug. 0·3 | — | Warm equable, dry. |
| *Zanzibar* | 6°15′ S. | 39°13′ E. | 69 | 79 | 81 | 76 | 96 | 69 | 82 | 82 | 61·5 | April 13·6 | Aug. 1·7 | 133 | Hot rainy. |
| AUSTRALASIA. | | | | | | | | | | | | | | | |
| *Australia—* | | | | | | | | | | | | | | | |
| *Federal Territory—* | | | | | | | | | | | | | | | |
| Canberra | 35°20′ S. | 149°15′ E. | 1,920 | 56 | 69 | 43 | — | — | 56 | 84 | 23·3 | Uni | form. | 95 | Warm equable, mod. rainy. |
| *New South Wales—* | | | | | | | | | | | | | | | |
| Bourke | 30°13′ S. | 145°58′ E. | 361 | 69 | 85 | 52 | 114 | 31 | 44 | 74 | 13·5 | Feb. 1·6 | Aug. Sept. 0·8 | — | Warm dry. |
| Sydney | 33°52′ S. | 151°12′ E. | 138 | 63 | 72 | 53 | 100 | 39 | 71 | 69 | 47·5 | April 5·6 | Nov. 2·8 | 155 | Warm equable, rainy. |
| *Northern Territory—* | | | | | | | | | | | | | | | |
| Alice Springs | 23°38′ S. | 133°23′ E. | 1,925 | 74 | 88 | 57 | 107 | 27 | 27 | 44 | 11·2 | Jan. 1·8 | Aug. 0·4 | 32 | Warm dry. |
| Darwin | 12°28′ S. | 130°51′ E. | 97 | 83 | 84 | 77 | 99 | 60 | 75 | 51 | 61·7 | Jan. 15·8 | July 0·1 | 99 | Hot, rainy summer. |
| *Queensland—* | | | | | | | | | | | | | | | |
| Brisbane | 27°28′ S. | 153° 1′ E. | 125 | 69 | 77 | 59 | 100 | 39 | 74 | 67 | 45·3 | Jan. 6·5 | Aug. Sept. 2·0 | 128 | Warm equable, rainy. |
| Normanton | 17°39′ S. | 141° 5′ E. | — | 81 | 85 | 71 | 107 | 45 | 68 | 55 | 38·7 | Jan. 11·7 | July-Sept. 0·1 | 56 | Hot, mod. rainy summer. |
| Thursday Island | 10°34′ S. | 142°12′ E. | 21 | 81 | 82 | 78 | 94 | 69 | 81 | 77 | 67·4 | Jan. 17·4 | Sept. 0·1 | 105 | Hot, rainy summer. |
| *South Australia—* | | | | | | | | | | | | | | | |
| Adelaide | 34°56′ S. | 138°35′ E. | 140 | 63 | 74 | 52 | 110 | 36 | 44 | 75 | 20·9 | June 3·1 | Jan. Feb. 0·7 | 124 | Warm equable, mod. rainy |
| *Victoria—* | | | | | | | | | | | | | | | |
| Melbourne | 37°49′ S. | 144°58′ E. | 115 | 58 | 67 | 49 | 105 | 31 | 60 | 78 | 25·6 | Oct. 2·7 | Feb. 1·7 | 140 | Warm equable, mod. rainy. |
| *West Australia—* | | | | | | | | | | | | | | | |
| Broome | 17°57′ S. | 122°15′ E. | 63 | 80 | 86 | 70 | 106 | 47 | 71 | 49 | 24·1 | Jan. 6·2 | Oct. 0·0 | 42 | Hot dry. |
| Perth | 31°57′ S. | 115°50′ E. | 197 | 64 | 74 | 55 | 105 | 38 | 52 | 72 | 33·9 | June 6·9 | Jan. 0·3 | 119 | Warm equable, mod. rainy. |

## Climatic Tables—*continued*

| Place. | Lat. | Long. | Height. | Mean Temperature. Year. | Jan. | July. | Mean Annual. Max. | Min. | Relative Humidity. Jan. | July. | Rainfall. Year. | Wettest Month. | Driest Month. | Days of Rain. | Climatic Character. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | feet. | ° F. | ° F. | ° F. | ° F. | ° F. | % | % | inches. | inches. | inches. | | |
| *Tasmania*— | | | | | | | | | | | | | | | |
| Hobart | 42°53′ S. | 147°20′ E. | 177 | 54 | 62 | 46 | 96 | 31 | 55 | 75 | 23·8 | Nov. 2·5 | Feb. 1·5 | 149 | Warm equable, mod. rainy. |
| *New Guinea*— | | | | | | | | | | | | | | | |
| Port Moresby | 9°29′ S. | 147° 9′ E. | 126 | 80 | 82 | 78 | 95 | 69 | 72 | 78 | 40·5 | Feb. 8·3 | Aug. 0·7 | 98 | Hot, mod. rainy. |
| *New Zealand*— | | | | | | | | | | | | | | | |
| Auckland | 36°50′ S. | 174°54′ E. | 125 | 59 | 66 | 52 | 81 | 37 | 77 | 82 | 44·9 | July 5·1 | Jan. 2·6 | 188 | Warm equable, rainy. |
| Christchurch | 43°32′ S. | 172°37′ E. | 32 | 53 | 62 | 43 | 88 | 25 | 72 | 81 | 25·2 | July 2·7 | Oct. 1·7 | 125 | Warm equable, mod. rainy. |
| Dunedin | 45°52′ S. | 170°32′ E. | 240 | 51 | 58 | 43 | 84 | 29 | 74 | 78 | 38·0 | Dec. 3·6 | Feb. 2·8 | 160 | Warm equable, rainy. |
| Wellington | 41°16′ S. | 174°46′ E. | 415 | 55 | 63 | 48 | 80 | 32 | 72 | 78 | 39·9 | July 4·5 | Feb. 2·5 | 167 | Warm equable, rainy. |
| ISLANDS. | | | | | | | | | | | | | | | |
| *Ascension Island* | 7°56′ S. | 14°25′ W. | 55 | 77 | 77 | 76 | 91 | 68 | 74 | 69 | 5·9 | April 1·5 | Dec. 0·1 | 64 | Hot dry. |
| *Azores*— | | | | | | | | | | | | | | | |
| Ponta Delgada | 37°44′ N. | 25°40′ W. | 118 | 64 | 58 | 70 | 80 | 46 | 77 | 76 | 28·5 | Nov. 3·4 | July 0·8 | 143 | Warm equable, mod. rainy |
| *Canary Islands*— | | | | | | | | | | | | | | | |
| Las Palmas. | 28° 7′ N. | 15°26′ W. | 39 | 69 | 64 | 72 | 90 | 50 | 72 | 75 | 9·6 | Nov. 2·2 | June 0·0 | 47 | Warm equable, dry. |
| *Caroline Islands*— | | | | | | | | | | | | | | | |
| Yap | 9°30′ N. | 138° 8′ E. | 96 | 80 | 80 | 80 | 94 | 71 | 81 | 86 | 119·1 | July 17·4 | April 5·0 | 259 | Hot, v. rainy. |
| *Fiji Islands*— | | | | | | | | | | | | | | | |
| Suva | 18° 8′ S. | 178°26′ E. | 20 | 77 | 79 | 73 | 93 | 60 | 76 | 77 | 117·1 | Mar. 14·5 | July 4·9 | 244 | Hot, v. rainy. |
| *Hawaii*— | | | | | | | | | | | | | | | |
| Honolulu | 21°19′ N. | 157°52′ W. | 38 | 75 | 71 | 78 | 86 | 59 | 70 | 65 | 30·6 | Dec. 4·3 | June 1·0 | 175 | Hot, mod. rainy. |
| *Madeira*— | | | | | | | | | | | | | | | |
| Funchal | 32°38′ N. | 16°54′ W. | 82 | 65 | 60 | 71 | 89 | 47 | 64 | 65 | 25·4 | Nov. 4·9 | July Aug. } 0·1 | 66 | Warm equable, mod. rainy. |
| *Mauritius* | 20° 6′ S. | 57°32′ E. | 181 | 73 | 79 | 68 | 91 | 54 | 76 | 75 | 50·6 | Mar. 8·7 | Sept. 1·4 | 204 | Hot, mod. rainy. |
| *New Caledonia*— | | | | | | | | | | | | | | | |
| Noumea | 22°16′ S. | 166°27′ E. | 30 | 75 | 80 | 69 | 94 | 56 | 71 | 73 | 50·5 | Mar. 7·7 | Sept. 1·3 | 127 | Hot rainy. |
| *Samoa*— | | | | | | | | | | | | | | | |
| Apia | 13°48′ S. | 171°46′ W. | 7 | 78 | 79 | 77 | 90 | 66 | 85 | 82 | 106·9 | Jan. 16·8 | July 2·6 | 188 | Hot rainy. |
| *Seychelles*— | | | | | | | | | | | | | | | |
| Mahe | 4°37′ S. | 55°27′ E. | 15 | 80 | 80 | 78 | 88 | 72 | 81 | 76 | 95·6 | Jan. 16·0 | Aug. 2·2 | — | Hot, rainy summer. |
| *Solomon Islands*— | | | | | | | | | | | | | | | |
| Tulagi | 9° 5′ S. | 160°10′ E. | 8 | 81 | 82 | 81 | 94 | 72 | 81 | 81 | 120·8 | Feb. 16·2 | June 6·6 | 221 | Hot, v. rainy. |
| *Spitsbergen*— | | | | | | | | | | | | | | | |
| Green Harbour | 78° 2′ N. | 14°15′ E. | 36 | 19 | 3 | 42 | 55 | −43 | 81 | 81 | 11·7 | Dec. 1·5 | June 0·4 | 114 | Cold snowy. |
| *Tahiti*— | | | | | | | | | | | | | | | |
| Papeete | 17°32′ S. | 149°34′ W. | 302 | 79 | 81 | 76 | 93 | 64 | 79 | 77 | 72·3 | Dec. 15·7 | July 1·4 | 130 | Hot rainy. |

# APPENDIX II

## MEASURES OF HUMIDITY

| Air Temperature. | Relative Humidity. | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 100% | | 60% | | | 20% | | |
| | Water content. | Vapour pressure. | Dew point. | Wet bulb. | Saturation deficit. | Dew point. | Wet bulb. | Saturation deficit. |
| ° F. | gr./cu.ft. | mb. | ° F. | ° F. | gr./cu.ft. | ° F. | ° F. | gr./cu.ft. |
| 140 | 58·5 | 199 | 121 | 123 | 23·4 | 84 | 97 | 46·8 |
| 135 | 51·4 | 175 | 116 | 118 | 20·6 | 80 | 93 | 41·1 |
| 130 | 45·1 | 153 | 111 | 114 | 18·0 | 76 | 90 | 36·1 |
| 125 | 39·4 | 134 | 107 | 110 | 15·8 | 72 | 87 | 31·5 |
| 120 | 34·5 | 117 | 102 | 105 | 13·8 | 68 | 83 | 27·6 |
| 115 | 30·1 | 101 | 98 | 101 | 12·0 | 64 | 80 | 24·1 |
| 110 | 26·3 | 88 | 93 | 96 | 10·5 | 60 | 77 | 21·0 |
| 105 | 23·0 | 76 | 88 | 92 | 9·2 | 56 | 74 | 18·4 |
| 100 | 20·0 | 65 | 84 | 88 | 8·0 | 52 | 71 | 16·0 |
| 95 | 17·3 | 56 | 79 | 83 | 6·9 | 48 | 68 | 13·8 |
| 90 | 15·0 | 48 | 74 | 79 | 6·0 | 44 | 65 | 12·0 |
| 85 | 12·9 | 41 | 69 | 75 | 5·2 | 40 | 62 | 10·3 |
| 80 | 11·1 | 35 | 65 | 70 | 4·4 | 36 | 58 | 8·9 |
| 75 | 9·5 | 30 | 60 | 66 | 3·8 | 32 | 55 | 7·6 |
| 70 | 8·1 | 25 | 55 | 62 | 3·2 | 28 | 52 | 6·5 |
| 65 | 6·9 | 21 | 51 | 57 | 2·8 | 24 | 48 | 5·5 |
| 60 | 5·8 | 18 | 46 | 53 | 2·3 | 20 | 45 | 4·6 |
| 55 | 4·9 | 15 | 41 | 49 | 2·0 | 16 | 42 | 3·9 |
| 50 | 4·1 | 12 | 36 | 44 | 1·6 | 12 | 38 | 3·3 |
| 45 | 3·4 | 10 | 32 | 40 | 1·4 | 9 | 34 | 2·7 |
| 40 | 2·9 | 8 | 28 | 35 | 1·2 | 5 | 30 | 2·3 |
| 35 | 2·4 | 7 | 23 | 31 | 1·0 | 1 | 27 | 1·9 |
| 30 | 1·9 | 6 | 19 | 27 | 0·8 | −3 | 23 | 1·5 |
| 25 | 1·5 | 5 | 14 | 22 | 0·6 | −7 | 19 | 1·2 |
| 20 | 1·2 | 4 | 9 | 17 | 0·5 | −11 | 15 | 1·0 |

# APPENDIX III

# CONVERSION FACTORS

*Length*

1 metre = 39·37 inches = 3·281 ft. = 1·0936 yds.
1 inch = 2·540 centimetres. 1 foot = 0·3048 metres. 1 yard = 0·9144 metres.
1 kilometre = 0·6214 miles. 1 mile = 1·609 km.

*Area*

1 sq. metre = 10·76 sq. ft. = 1·196 sq. yds. 1 sq. ft. = 0·0929 sq. metre.
1 hectare = 2·471 acres. 1 acre = 0·4047 hectares.
1 acre = 4,840 sq. yds.
1 sq. km. = 0·3861 sq. mile. 1 sq. mile = 2·590 sq. km.

*Volume*

1 cu. cm. (c.c.) = 0·061 cu. in. 1 cu. in. = 16·4 c.c.
1 cu. metre = 35·3 cu. ft. = 1·31 cu. yds. 1 cu. yd. = 0·764 cu. metre.
1 litre = 61·025 cu. ins. = 0·88 quart. 1 qt. = 1·1365 litres.
1 acre-inch (inch per acre) = 3,630 cu. ft.

*Weight*

1 gram = 15·432 grains = 0·0353 oz. 1 grain = 0·0648 gram. 1 oz. = 28·35 grams.
1 kilogram = 2·2046 lbs. (av.). 1 lb. = 0·4536 kg.
1 ton (2,240 lbs.) = 1·064 metric tonne. 1 metric tonne (1,000 kg.) = 2,204·6 lbs. = 0·984 ton.
1 gm./cu. metre = 0·437 grains/cu. ft. 1 grain/cu. ft. = 2·29 gm./cu. metre.

*Energy*

1 kg./cal. (Cal.) = 1,000 gm./cal. = 3·968 B.T.U. 1 B.T.U. = 252 gm./cal.
1 gm./cal./cm.$^2$ = 3·69 B.T.U./sq. ft.
1 joule = 0·24 gm./cal.

*Velocity*

1 ft./sec. = 0·682 m.p.h. = 0·305 metre/sec.
1 metre/sec. = 2·237 m.p.h. = 3·281 ft./sec. 1 m.p.h. = 0·447 metre/sec.
1 Knot = 1·1515 m.p.h.

*Force*

1 kg./sq. metre = 0·205 lb./sq. ft. 1 lb./sq. ft. = 4·88 kg./sq. metre.

*Illumination*

1 lux = 0·0929 ft.-candles. 1 ft.-candle = 10·764 lux.

*Temperature*

$\theta°$ C. = $(32 + 1{\cdot}8\theta)$ ° F. $t°$ F. = $(5t/9 - 32)$ ° C.
$T°$ Absolute = $273 + \theta°$ C.

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